

Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools

Committee on Programs for Advanced Study of Mathematics and Science in American High Schools, National Research Council

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LEARNING AND UNDERSTANDING

IMPROVING ADVANCED STUDY OF MATHEMATICS AND SCIENCE IN U.S. HIGH SCHOOLS

Committee on Programs for Advanced Study of Mathematics and Science
in American High Schools

Jerry P. Gollub, Meryl W. Bertenthal,
Jay B. Labov, and Philip C. Curtis, Editors

Center for Education

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National Research Council

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Preface

The United States has compiled a remarkable record of excellence and leadership in science, mathematics, and technology over the past half century. Effective mathematics and science education at the advanced high school level is critical if this record is to continue. In addition, quality science and mathematics education is important in preparing students to succeed in higher education and to be informed citizens.

This report is the product of a 2-year study of programs for advanced science and mathematics education in U.S. high schools. Recent research on learning and program design served as the basis for the analysis. This emerging knowledge was used to evaluate the Advanced Placement (AP) and International Baccalaureate (IB) programs and to examine specific ways in which these and other programs of advanced study can be made more effective and more accessible to all students who might benefit from them.

The study committee comprised professional educators, teachers with experience in the AP and IB programs, university scientists and mathematicians, experts in learning and talent development, and authorities on access and equity in education. Their diverse perspectives resulted in an interdisciplinary approach to the analysis and assessment of programs for advanced study. We appreciate the cooperative efforts of the study committee to achieve a balance among these different perspectives.

This study was particularly complex for several reasons. First, the committee was charged by the National Research Council (NRC) to consider advanced study in depth in four disciplines: biology, chemistry, physics, and mathematics (with an emphasis on calculus). The committee therefore convened diverse panels of experts in each of these fields, and their extensive reports form an important part of the study results, grounding the analysis in the classroom practice of advanced study programs.¹ A second source of complexity in the study was the fact that the AP and IB programs must be

¹The four panel reports are available online as pdf files at www.nap.edu/catalog/10129.html.

examined in the context of the entire system of education in the United States. These programs have important effects on school curricula and staffing starting in the middle-school years, and they also influence and are shaped by trends in higher education. A third source of complexity was the dilemma of how to deal with extensive disparities in access to advanced study that have the effect of excluding many students, especially minorities and residents of impoverished communities, while continuing to ensure that traditionally advantaged students are served effectively.

All members of the committee contributed generously to the study, both to discussions held during and between meetings, and, by providing draft text or comments, to the process of preparing this report. Four committee members also served as panel chairs, drafted the respective panel reports, and responded to reviews: William Wood, biology panel; Conrad Stanitski, chemistry panel; Robin Spital, physics panel; and Deborah Hughes Hallett, mathematics panel. Their exceptional efforts contributed substantially to the success of this project. We also acknowledge important scholarly work on access and equity by Valerie Lee and Jeannie Oakes. In addition, we note the central contributions of Camilla Benbow, Hilda Borko, John Dossey, Stephanie Pace Marshall, Michael Martinez, and Joseph Novak, who as a group developed the material presented in Chapters 6 and 7 and guided the analyses of Chapters 8 and 9. We thank David Ely, Patsy Mueller, Robin Spital, and Wanda Bussey, the members of the committee who are teachers of the AP and IB programs, for helping the committee understand today's high school settings. Finally, we acknowledge Glenn Crosby's contributions to our discussions of teacher education and professional development.

The NRC's Center for Education provided exceptional support for this project. Project director Jay Labov and senior program officer Meryl Bertenthal worked tirelessly to seek out the extensive information required by the study committee and to help overcome obstacles to achieving consensus. They also contributed substantially to the process of drafting this report and guiding the panel reports successfully through the stringent NRC review process. We appreciate as well the capable efforts of John Shephard and Andrew Tompkins, our research and project assistants. Leslie Ann Pierce, an experienced AP and IB teacher, served as consultant to the committee and contributed to the report. Program officer Marilee Shelton and consultant Billy Goodman assisted in the early phases of the project.

We acknowledge the helpfulness of the staff of the AP and IB, who provided the committee with extensive information. Their commitment to the long-term improvement of these programs and their receptiveness to the committee's ideas were evident. Although this report constitutes a strong critique in many respects, its recommendations should not be regarded either as questioning the importance of these programs or as conflicting with improvement efforts already in progress. The active collaboration of many

different groups will be required to implement the recommendations of this study.

This study is part of a major commitment by the NRC to use its expertise in the service of science and mathematics education. The committee anticipates that the report will be useful to all those concerned with improving educational quality and equity, including program developers, science and mathematics teachers, university scientists, policymakers, school administrators, and parents.

Jerry W. Gollub and Philip C. Curtis, *Cochairs*

Acknowledgments

The committee and staff thank the many individuals and organizations that gave generously of their time and expertise to help with this study.

First, we acknowledge the support of the National Science Foundation and the U.S. Department of Education, Office of Educational Research and Improvement. We particularly thank Janice Earle of the National Science Foundation and Patricia Ross of the Office of Educational Research and Improvement of the Department of Education for the support and encouragement they provided to this committee during the past 36 months.

We acknowledge the important contributions of the 22 individuals who, as members of four disciplinary content panels, conducted in-depth analyses of the Advanced Placement (AP) and International Baccalaureate (IB) programs in mathematics, chemistry, biology, and physics. Our sincerest thanks go to Robert A. Bloodgood, University of Virginia; Harold Boger, Crenshaw High School, Los Angeles, California; Marilyn P. Carlson, Arizona State University; Mary P. Colvard, Cobleskill-Richmond High School, NY; Patrick G. Ehrman, University of Washington; Arthur B. Ellis, University of Wisconsin, Madison; S. James Gates, Jr., University of Maryland, College Park; David M. Hammer, University of Maryland, College Park; Robert C. Hilborn, Amherst College; Roger Howe, Yale University; John Jungck, Beloit College; Eric Mazur, Harvard University; Patricia Metz, United States Naval Academy; Robert A. Morse, St. Albans School, Washington, DC; Penny Moore, Ohio State University; John C. Oliver, Lindbergh High School, St. Louis, Missouri; David Pysnik, Sydney High School, Sydney, New York; Truman Schwartz, Macalester College; Daniel J. Teague, North Carolina School of Science and Mathematics, Durham, North Carolina; Glenda M. Torrance, Montgomery Blair High School, Silver Spring, Maryland; Alan C. Tucker, State University of New York, Stony Brook; and James H. Wandersee, Louisiana State University.

We are grateful to Lee Jones, director of the AP program, and Paul Campbell, associate director of the International Baccalaureate Organisation

of North America (IBNA), for providing program materials and data throughout the study. They attended several committee meetings and workshops as invited guests, organized presentations to the committee, and answered ongoing questions about their respective programs. Their cooperation was critical to our efforts.

When this study began, the IB program was less familiar than the AP program to most committee members. We thank the many individuals who provided the committee with in-depth information about the IB program. David Roylance, IB coordinator, Jeb Stuart High School in Fairfax, Virginia, presented an overview of the IB program model. The committee obtained insight into the structure, organization, and goals of IB science and mathematics curricula, instructional models, assessment, and professional development opportunities from Jonathan Knopp, Rufus King High School, Milwaukee, Wisconsin; Ken Fox, Smoky Hill High School, Aurora, Colorado; Arden Zipp, State University of New York at Courtland; and IBNA associate director Paul Campbell. We acknowledge as well the ongoing help received from IBNA staff members George Pook, Roger Brown, Jeff Thompson, and Helen Drennen.

Individually and collectively, members of the committee benefited from discussions with experts in a variety of fields. We especially thank James Pellegrino, University of Illinois at Chicago, and José Mestre, University of Massachusetts at Amherst, who helped expand our understanding of the relevance of research on human cognition to the design and evaluation of advanced study programs. Their advice helped the committee conceptualize the model presented in this report for the design and evaluation of advanced study programs.

Results from the *Third International Mathematics and Science Study (TIMSS)* contributed to the motivation for this study. We wish to thank Michael Martin, TIMSS international deputy study director, and Patrick Gonzales, National Center for Education Statistics, U.S. Department of Education, for helping the committee understand the *TIMSS* results.

Many individuals aided the committee's work by participating in a series of information-gathering workshops that were held in conjunction with several of the committee's meetings. The following individuals participated in a committee workshop addressing the design and development of AP programs and assessments in mathematics and science: Dr. John Smarrelli, chair, AP Biology Committee, Loyola University, Chicago; Dr. Robert Cannon, chief faculty consultant, AP Biology, University of North Carolina at Chapel Hill; Dr. Thomas P. Dick, chair, AP Calculus Committee, Oregon State University; Dr. Larry Riddle, chief faculty consultant, AP Calculus, Agnes Scott College; Dr. William H. Ingham, chair, AP Physics Committee, James Madison University; Patrick Polley, chief faculty consultant, AP Physics, Beloit College; Beth Nichols, assessment specialist, Educational Testing Service; Chancey Jones,

assessment specialist, Educational Testing Service; Ann Marie Zolandz, assessment specialist, Educational Testing Service; and Rick Morgan, measurement statistician, Educational Testing Service. Howard Everson, The College Board vice-president for Teaching and Learning, was also instrumental in helping the committee understand the mission and goals of the AP program.

Bernard L. Madison, professor of mathematics, University of Arkansas, Fayetteville, and a member of the College Board's Commission on the Future of the Advanced Placement Program, provided the committee with an overview of the commission's findings and recommendations.

Three individuals—Peter O'Donnell, president of the O'Donnell Foundation in Dallas, Texas; Carolyn Bacon, executive director of the Foundation; and Gregg Fleisher, president, Advanced Placement Strategies—spoke with the committee about an innovative program that engages students, teachers, and schools in an effort to increase the number of traditionally underrepresented Texas students who take AP courses and succeed on AP examinations.

We also acknowledge several consultants who contributed significantly to the project. Carolyn Callahan, University of Virginia, helped the committee understand the roles of AP and IB in meeting the needs of gifted and talented students. Karen Boeschstein, Office of Undergraduate Admission at the University of Virginia, assisted the committee in interpreting data that was gathered through an informal survey of deans of admission (see Chapters 2 and 10). Bert Green, The Johns Hopkins University, helped the committee with an independent evaluation and interpretation of the College Board's AP validity studies (see Chapter 10). Julie Heifetz, Moss Rehabilitation Center in Philadelphia, Pennsylvania, interviewed AP and IB students from different schools.

Many individuals within the National Research Council (NRC) assisted the committee. We are grateful for the support of Bruce Alberts, president of the National Academy of Sciences, who took a particular interest in this study and provided support and encouragement along the way. Alexandra Beatty drafted the original proposal for the project, and Richard Noeth was study director in the early months of the project. We thank Michael Feuer, director of the Center for Education, for his support and encouragement, and Kirsten Sampson Snyder, who shepherded the four panel reports and the main committee report through the NRC review process, and Yvonne Wise for processing the report through final production. Genie Grohman gave valuable assistance in thinking about the organization of this report, and Judy Koenig contributed to the assessment sections of the report. Rona Briere capably edited the final version. Naomi Chudowsky, study director of the Cognitive Foundations of Assessment Committee, shared with us early drafts of her committee's report and consulted with us about our conceptual model for the design and evaluation of advanced study programs. Brenda

Buchbinder managed the finances of the project, and Viola Horek, administrative officer for the Center for Education, provided important assistance.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Royce W. Murray and Melvin C. George. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

In addition, the following individuals served as reviewers for the four panel reports included as supporting documentation in this volume:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of the panel reports, nor did they see the final drafts of the reports before their release. The review of these reports was overseen by Philip C. Curtis. Appointed by the NRC, he was responsible for making certain that an independent examination of these reports was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of these reports rests entirely with the authoring panels and the institution.

As a final note, we would like to acknowledge that when copyright permissions were being sought from various sources, the IBO pointed out several inaccuracies in our listing of their programs. Since this report was already in the final stages of printing when these errors were noted, we correct them here for the entire report and extend our apologies to the IBO: The “program guides” to which we refer throughout the main report as well as the content panel reports should instead be labeled as “subject guides” in specific disciplines (e.g., Chemistry guide). The IB Diploma Programme is one of three academic programs. The IBO is now using the U.S. spelling of “Organization” as part of its official name rather than “Organisation” that is presented throughout this report. Finally, it also should be noted that permission to reprint AP materials does not constitute review or endorsement by the Educational Testing Service or the College Board of this publication as a whole or of any questions or testing information it may contain.

Contents

EXECUTIVE SUMMARY	1
1. INTRODUCTION	17
Background, 18	
Brief Overview of the Programs, 20	
What Is Advanced Study?, 22	
The Student Clientele for Advanced Study, 23	
Study Charge and Approach, 24	
Audiences for the Report, 26	
Overview and Structure of the Report, 26	
2. CONTEXT OF ADVANCED STUDY	28
Policy Context, 29	
Educational Context, 36	
Disparities in Opportunities to Pursue and Succeed in Advanced Study, 47	
Connections Between Advanced Study and Higher Education, 51	
Epilogue, 63	
3. THE ADVANCED PLACEMENT PROGRAM	64
Overview, 64	
AP Curriculum, 66	
AP Instruction, 71	
AP Assessment, 75	
AP Professional Development, 79	

4. THE INTERNATIONAL BACCALAUREATE PROGRAMME	83
Overview, 83	
IB Curriculum, 86	
IB Instruction, 92	
IB Assessment, 94	
IB Professional Development, 100	
5. OTHER OPPORTUNITIES AND APPROACHES TO ADVANCED STUDY	103
Alternatives for Providing College-Level Learning in High School, 103	
Enrichment Activities, 113	
Conclusion, 116	
6. LEARNING WITH UNDERSTANDING: SEVEN PRINCIPLES	117
Seven Principles of Human Learning, 118	
Conclusion, 129	
ANNEX 6-1 Characteristics of High-Ability Learners and Implications for Curriculum and Instruction, 130	
7. DESIGNING CURRICULUM, INSTRUCTION, ASSESSMENT, AND PROFESSIONAL DEVELOPMENT	134
Curriculum, 135	
Instruction, 137	
Assessment, 141	
Teacher Professional Development, 146	
From Framework to Advanced Study Programs, 152	
8. ANALYSIS OF THE AP AND IB PROGRAMS BASED ON LEARNING RESEARCH	154
Principled Conceptual Knowledge, 156	
Prior Knowledge, 160	
Metacognition, 164	
Differences Among Learners, 166	
Motivation, 168	
Learning Communities, 170	
Learning in Context, 172	
Concluding Remarks, 174	

9. ANALYSIS OF AP AND IB CURRICULUM, INSTRUCTION, ASSESSMENT, AND PROFESSIONAL DEVELOPMENT	176
Curriculum, 176	
Instruction, 178	
Assessment, 180	
Professional Development, 183	
Conclusion, 184	
10. USES, MISUSES, AND UNINTENDED CONSEQUENCES OF AP AND IB	185
High Stakes, 185	
Quality Control, 188	
Access and Equity, 191	
College Credit and Placement, 192	
Conclusion, 196	
11. RECOMMENDATIONS	197
Recommendation 1: The Primary Goal of Advanced Study, 197	
Recommendation 2: Access and Equity, 198	
Recommendation 3: Learning Principles, 199	
Recommendation 4: Curriculum, 199	
Recommendation 5: Instruction, 200	
Recommendation 6: Assessment, 201	
Recommendation 7: Qualified Teachers and Professional Development, 201	
Recommendation 8: Alternative Programs, 202	
Recommendation 9: The Secondary–College Interface, 202	
Recommendation 10: Changes in the AP and IB Programs, 203	
REFERENCES	206
APPENDIX A: Overview of Panel Findings and Recommendations	229
APPENDIX B: Biographical Sketches of Committee Members	253

APPENDIX C: Statement of Task	259
INDEX	261
CONTENT PANEL REPORTS*	
Biology	273
Chemistry	337
Physics	393
Mathematics	483

*Content Panel Reports are not printed in this volume but are available online. Go to <http://www.nap.edu> and search for *Learning and Understanding*.

LEARNING AND UNDERSTANDING

Executive Summary

This report presents results of a 2-year effort by a National Research Council (NRC) committee to examine programs for advanced study of mathematics and science in U.S. high schools. The committee focussed on the two most widely recognized programs in the United States, and the only two of national scope: Advanced Placement (AP) and International Baccalaureate (IB). The committee also identified alternatives to IB and AP and addressed specific questions about advanced study.¹ The committee's statement of task and study questions are found in Appendix C.

While international comparisons of the performance of advanced students served as a catalyst for the study, its primary motivator was the improved, research-based understanding of teaching and learning that has emerged recently, and its application to improving advanced study. In approaching its charge, the committee considered advances in the cognitive and learning sciences. The committee also examined research about the AP and IB programs using information provided by the College Board and the International Baccalaureate Organisation (IBO). Neither the AP or IB programs nor independent researchers, however, have yet gathered or published critical data that the committee sought. Therefore, the committee also relied on materials and expert testimony from AP and IB program officials and teachers for some of the data used in its analyses. More studies are needed to address the many issues that are raised by this report.

¹The committee found that defining "advanced study" for secondary students is surprisingly difficult. Establishing a clear definition is problematic in part because these programs share a number of the objectives of other high school courses. Although many equate accelerated content (e.g., college-level material) with secondary-school advanced study, the committee concluded that acceleration alone does not define a quality program. Indeed, the inclusion of too much accelerated content can prevent students from achieving the primary goal of advanced study: deep conceptual understanding of the content and unifying concepts of a discipline.

The committee found that existing programs for advanced study are frequently inconsistent with the results of the research on cognition and learning. This report describes how program developers, schools, and educators can remedy this situation by considering all components of educational programs: curriculum, instruction, ongoing and end-of-course assessments, and teacher preparation and professional development.

Also examined in depth is the issue of equal access to advanced study. Advanced study is no longer only for an elite audience of exceptionally talented and privileged students; participation has become almost the norm for students seeking admission to selective colleges. Yet minorities, inner-city and rural students face serious limitations in accessing programs. These broader populations of students who could benefit from advanced study are currently limited by their prior educational opportunities, their schools' ability to provide effective learning environments, and the availability of qualified and effective teachers. Improvements in these areas could significantly expand the population that can be served effectively by advanced study.

Expertise on the committee included scientist-researchers, secondary teachers of AP and IB, science and mathematics educators working on teacher education and issues of access and equity, cognitive scientists, and educational administrators. Panels of experts in the disciplines (biology, chemistry, physics, and mathematics) also advised the committee. The four panel reports provided a critical basis for the committee's analysis and may be used independently of this volume. They are available online² and are summarized in Appendix A.

This report is intended for many audiences concerned with high school science and mathematics education in general and advanced study in particular, including program developers, high school and higher education faculty, university and high school administrators, policymakers, and parents.

CONTEXT OF ADVANCED STUDY

Advanced study has wide-ranging effects on curricula, teachers, and students, therefore, advanced courses must be considered within a broader context that includes the schools where the courses are offered, preceding grade levels, and higher education. Advanced study in science and mathematics makes special demands on facilities, financial resources, and personnel at both the middle- and high school levels.

²At <http://www.nap.edu/catalog/10129.html>.

Components

Teachers. Students learn best from teachers with strong content knowledge and pedagogical skills. Lack of access to high-quality teachers may preclude some students, especially minorities and those living in poverty, from pursuing advanced study. All 50 states require licensing of public school teachers; none requires special certification for those providing advanced study. High school teachers see themselves as subject area specialists. They teach up to 175 students per day, and have little opportunity to work with colleagues to improve curriculum or instruction. They frequently cite inadequate support, lack of student motivation, and student discipline problems as reasons for leaving teaching.

Coordination. Academic preparation for advanced study begins in middle school. Mathematics and science courses in these grades often lack focus, cover too many topics, repeat material, and are implemented inconsistently. In mathematics, states are moving toward offering algebra in eighth grade. Increasing numbers of middle schools are instituting integrated science curricula that de-emphasize disciplines. Middle and high school teachers rarely have opportunities to coordinate curricula or instruction for grades 7–12.

Curricular Differentiation. More than 80 percent of middle schools and many high schools direct or allow students to choose their classes in mathematics, science, and other subjects. Other schools offer core curricula that are narrowly focused on academic subjects and allow students few choices. Early differential placement steers some students away from rigorous academic programs. Research indicates that constrained curricula are more effective and equitable in helping students pursue advanced study.

Sequencing. The typical progression of courses in high school mathematics leading to calculus is Algebra I, geometry, Algebra II, trigonometry, and precalculus. Most state high school graduation requirements also include 2 years of science, although college-bound students traditionally take more, usually biology, chemistry, and then physics.

Standards. In science, standards developed by the American Association for the Advancement of Science and the National Research Council call for increased emphasis on inquiry and in-depth study of fewer topics. In mathematics, the standards from the National Council of Teachers of Mathematics emphasize learning of concepts and helping students understand mathematics more deeply. Forty-nine states have developed standards and

curriculum frameworks in mathematics and science. All 50 states test their students and 27 states hold schools accountable for results. The AP and IB programs are not predicated on state or national standards in any subject area, but can complement standards-based reform efforts. Both provide nationally recognized external measures of student achievement, but schools can implement the programs in ways that conform to local or state standards.

Students. High school students face competing time pressures. Typical students work 15–20 hours per week, spend 20–25 hours socializing, 5 hours in extracurricular activities, and 15 hours watching television. Significant numbers of students—particularly those from low-income families—think so much about problems at home that they cannot concentrate in school.

Unequal Access

There is an enduring belief that advanced study confers advantages to students in college; thus, ever-increasing numbers enroll in AP courses and IB programs. However, access to advanced study is uneven. Some high schools offer multiple sections in many AP subjects; others provide none. These differences are associated with school size and location, and the availability of AP and IB in a school decreases as the percentage of minority or low-income students increases, especially in mathematics and science. Even where available, students from underrepresented and low-income groups take advanced courses less frequently than students from other groups. Effective strategies for improving student participation in advanced study include eliminating low-level courses with reduced academic expectations, enhancing professional development for teachers, hiring qualified teachers for rural and inner-city schools, providing information to parents about long-term benefits of participating in such programs, and increasing student access to skilled counselors and mentors.

High School–College Interface

To understand the role AP and IB play in college admission decisions, the committee surveyed deans of admission. The survey revealed that participation in these programs is of greatest importance for admission to the most selective colleges. Deans view such participation as an indication of students' willingness to accept academic challenges, but stated that the lack of such courses at an applicant's high school typically does not adversely influence admission if a student succeeded in the most challenging courses available at his or her school.

AP and IB examinations are administered each May, but scores are not available until July. Therefore, examination grades from the senior year do not influence college admission, but are used in credit and placement decisions. Students also use these credits to reduce course loads or to meet prerequisite or distribution requirements. As a result, some students may not have to take college courses in specific subject areas, such as mathematics or science. Some institutions minimize this practice by requiring that students enroll in courses at higher levels than those taken in high school. A survey of mathematics and biology departments revealed that the vast majority award credit and advanced placement for AP, and sometimes IB; the amount awarded usually depends on the student's score.

OVERVIEW OF THE PROGRAMS

Advanced Placement

Developed in 1955, AP is the predominant national program for advanced courses in U.S. high schools. Eleven separate courses are available in eight mathematics and science subjects. The College Board provides topic outlines for AP courses, generated largely by surveying colleges and universities. However, teachers are allowed considerable leeway in implementation. Elective, end-of-course examinations are designed to be comparable with "typical" introductory college-level courses in a subject area. Originally, the program served only top students from a few high schools. Today, approximately 62 percent of U.S. high schools offer AP. In May 2001, students took more than 450,000 AP examinations in mathematics and science.

International Baccalaureate

The IB program was developed in the late 1960s to provide an international standard of secondary education for children of diplomats and others stationed outside their countries. One goal was to prepare students for university work in their home countries. The IBO authorizes participating high schools; schools must offer a full IB Diploma Programme and cannot offer only a subset of IB courses. While some students take individual IB courses as they would an honors course, most are diploma candidates, taking a program of six or seven courses over two years.

Final examinations are part of the integrated IB Diploma Programme. Assessment consists of both external and internal components designed to measure content knowledge, depth of understanding, and use of specific higher-level cognitive skills for each subject. In May 2001, students from 272 U.S. public and private schools took 50,745 IB examinations, of which roughly 13,000 were in mathematics and science. Teachers also provide internal as-

assessments of students' practical skills (for example, laboratory investigations in science, portfolios in mathematics), which are judged against established IBO assessment criteria.

Alternative Approaches

Other opportunities for advanced study in high school are available through local-, state-, and nationally sponsored programs. These include collaborative programs between high schools and postsecondary institutions, specialized schools for high-ability learners, distance learning programs, research internships, and academic competitions. Many programs award college credit to high school students, but less is known about transferability of credits earned in these alternate programs compared with qualifying scores on AP or IB examinations.

DESIGNING PROGRAMS BASED ON RESEARCH ON LEARNING AND PEDAGOGY

The goal of advanced study is to promote development of deep conceptual understanding and the ability to apply knowledge appropriately. Accordingly, the committee developed a framework to guide its analysis of advanced study and to evaluate the degree to which existing programs accomplish this goal. This model also can guide the development of new programs.

The concept of “learning with understanding” is concerned with knowledge and how it is organized. Effective instruction is focused on enabling learners to uncover and formulate the deep organizing patterns of a domain, and then to actively access and create meaning around these organizing principles. Learning with understanding also helps students develop the ability to evaluate the relevance of particular knowledge to novel problems and to explain and justify their thinking. As students learn and practice these skills of critical reflection, they become able to apply knowledge in multiple contexts, develop adaptive expertise, and serve as active members of learning communities.

Seven Principles of Human Learning

Seven research-based principles of learning can provide a framework for designing effective curriculum, instruction, and assessment—three facets of classroom activity that teachers can orchestrate to promote learning with understanding. These principles also underlie the design of effective preparation and professional development for teachers, which, along with cur-

riculum, instruction, and assessment, helps create a system that focuses on student learning:

1. Learning with understanding is facilitated when knowledge is related to and structured around major concepts and principles of a discipline.
2. A learner's prior knowledge is the starting point for effective learning.
3. Metacognitive learning (self-monitoring) is important for acquiring proficiency.
4. Recognizing differences among learners is important for effective teaching and learning.
5. Learners' beliefs about their ability to learn affect learning success.
6. Practices and activities in which people engage during learning shape what is learned.
7. Socially supported interactions strengthen one's ability to learn with understanding.

Design Principles: Curriculum, Instruction, Assessment, and Professional Development

The committee's framework for appraising advanced study programs encompasses the intentional and systematic design of curriculum, instruction, assessment, and professional development within the context of advanced study. Consideration of these program elements is based on the principles of learning and on theory and research on instructional programs. Education systems frequently address each element separately, but all four must be aligned and work together synergistically to facilitate deep conceptual understanding. The following examples of design principles for curriculum, instruction, and assessment reflect what is known about human learning:

- Effective mathematics and science curricula are coherent, focus on important ideas within the discipline, and are sequenced to optimize learning. They provide ample opportunities for exploring ideas in depth and for developing familiarity with the discourse and modes of inquiry of the discipline.
- Teaching for understanding begins with careful consideration of students' thinking. It employs multiple representations and tasks. Effective teachers create learning environments that foster development of students' understanding and skills. They orchestrate classroom discourse in which students conjecture, present solutions, and argue about the validity of claims.

- Assessment for understanding is aligned with instruction and with desired learning outcomes. It is multifaceted and continuous and includes both content and process dimensions of performance.

Successful implementation of advanced study that promotes learning with understanding also depends upon creating opportunities for teachers' continual learning, and requires sufficient resources to support professional development. Effective professional development for mathematics and science teachers emphasizes deep understanding of content and discipline-based methods of inquiry, provides multiple perspectives on students as learners, and develops teachers' subject-specific pedagogical knowledge. It treats teachers as active learners, builds on their existing knowledge and beliefs, and occurs in professional communities where there are opportunities to discuss ideas and practices as colleagues.

ANALYSIS OF AP AND IB PROGRAMS BASED ON LEARNING RESEARCH

Although the AP and IB programs predate contemporary learning research, it is important to use the principles emerging from that research to assess and improve the programs. The committee's analysis of these programs, based on these principles of learning and supported by the reports of the four disciplinary panels, yielded the following findings:

- *Principled conceptual knowledge*—Although the AP and IB programs espouse an emphasis on concepts and key ideas, this intention is largely unrealized in the sciences. Excessive breadth of coverage (especially in 1-year science programs) and insufficient emphasis on key concepts in final assessments contribute significantly to the problem in all science fields. Although emphasis on learning concepts and key ideas is more evident in mathematics, further improvement is needed, particularly in the assessments, which frequently focus on procedural knowledge at the expense of conceptual understanding.

- *Prior knowledge*—Except for mathematics, these programs do not specify clearly what prior knowledge is needed for success or help teachers to build on what students already know or to recognize student misconceptions. In all subjects, efforts to prepare students properly in the years preceding advanced study are often inadequate. Too many students, especially in physics, take a 1-year advanced course as their first course in the discipline—an inappropriate situation.

- *Metacognition*—Advanced study can increase students' metacognitive skills, but many programs and courses do not help students develop these skills.

- *Differences among learners*—AP and IB teachers who employ a variety of pedagogical approaches are likely to reach a broader range of learners. Using several sources of evidence of student progress also can provide a more accurate picture of what students know compared with any single measure, such as an examination. The single end-of-year examinations and summary scores, as found in AP, do not adequately capture student learning.
- *Motivation*—Students have varied motives for enrolling in advanced study. Designing programs that are consistent with the findings of learning research can increase students' motivation to succeed in advanced study, encourage them to believe in their own potential, and increase the proportion of students who take and succeed in the course and final examinations.
- *Learning communities*—Teamwork and collaborative investigation are especially important in advanced study. The breadth of course content and the generally short duration of laboratory periods in many schools may be inadequate for such activities. Better use of the Internet and technologies for collaborative learning is needed.
- *Situated learning*—Students need opportunities to learn concepts in a variety of contexts. The AP and IB programs currently do not emphasize interdisciplinary connections sufficiently or assess students' ability to apply their knowledge in new situations or contexts. Additionally, advanced study courses might make better use of laboratory experiences by requiring students to plan experiments, decide what information is important, select experimental methods, and review results critically. These courses might also draw upon local resources (e.g., science-related industries) to give students experience with varied practices in mathematics and science.

Although AP and IB programs currently are not well aligned with learning principles, they can be revised with this research in mind. The resulting transformations are likely to make the programs more successful in enhancing deep conceptual learning and make them more accessible to additional students.

ANALYSIS OF AP AND IB PROGRAMS WITH REGARD TO CURRICULUM, INSTRUCTION, ASSESSMENT, AND PROFESSIONAL DEVELOPMENT

Curriculum

Students can study topics in depth and develop conceptual understanding only if curricula do not present excessive numbers of topics. Currently, AP and IB programs are inconsistent with this precept. In their written materials the College Board and the IBO acknowledge the importance of depth

and focus, but the breadth of topics covered in their curriculum guides and assessments conveys a different message. Additionally, the College Board models AP course outlines on *typical* college introductory courses, rather than on the best college courses or educational practices based on research on learning and pedagogy. Since college-level courses vary substantially in content and pedagogy, this approach limits the potential quality of AP courses.

Instruction

Individual teachers have substantial leeway in implementing AP or IB courses. Therefore, the nature and quality of instruction vary considerably from classroom to classroom. AP and IB programs depart from the model of instruction outlined above by not providing adequate guidance concerning excellent teaching practices in advanced study.

Assessment

The central principle for designing assessments that foster deep conceptual understanding is that they must be aligned with learning goals and with curriculum and instruction derived from those goals. Because AP and IB assessments exert a powerful influence on curriculum and instruction, it is especially important to ensure that they are designed to foster deep conceptual understanding.

A striking inadequacy of the AP and IB programs is the lack of detailed research about what their examinations actually measure, including the kinds of thinking that the examinations elicit. This concern touches on the tests' validity and the appropriateness of the inferences drawn from test scores. For both the AP and IB programs, certain kinds of validity research are lacking, including attention to the broader social consequences (or consequential validity) of their assessments.

Because high-stakes assessments strongly influence instruction, it is imperative to understand the connections between assessment and instruction in both programs. If instruction is to enhance understanding, assessments should not be predictable from year to year, nor should their content or form be capricious. Assessments in some AP and IB courses are relatively predictable.

Professional Development

At present, neither the College Board nor the IBO supports systematic and continuing professional development for teachers. Professional development opportunities vary in quality and focus and do not consistently re-

flect the notions of learning, instruction, curriculum, and assessment presented in this report. The College Board does not adequately monitor professional development programs that support AP; teachers' participation in such programs is voluntary. The College Board and the IBO have made progress in providing Web-based resources, workshops, and mentorships, but many teachers still lack access to such resources and opportunities.

Accepting greater responsibility for teacher professional development is a daunting challenge for the College Board and the IBO, whose missions historically have been much more limited in focus. Without improved professional development, however, other efforts to improve advanced study are likely to founder.

USES, MISUSES, AND UNINTENDED CONSEQUENCES OF AP AND IB

Some misuses of AP and IB test scores may have unfortunate consequences, though these have not been studied in detail. For example, in an attempt to quantify the extent to which high schools challenge students, top public high schools have recently been ranked based on the number of AP and IB tests taken. AP and IB assessment data also have been used inappropriately to evaluate teachers or to compare schools. Because of this, the committee is concerned that teachers may emphasize to their students the mechanics of preparing for a test, rather than learning and understanding of important principles. Coverage of content may be superficial and opportunities for inquiry-based experiences insufficient. The committee also has learned that some teachers discourage students from taking AP or IB courses (or the final examinations) when poor performance is anticipated. This form of limiting access occurs in many educational settings, including the most competitive high schools.

Data from AP and IB test scores by themselves cannot support inferences about teacher quality and effectiveness. Students come to advanced courses with different levels of skill and mastery of content that make it difficult to determine the effects of a teacher's work on student achievement in any particular year. Nor should such data be used to measure school quality. Some schools offer other options that are equally rigorous but more suited to their students.

Unlike the IBO, the College Board has no clear standards as to what constitutes an AP course. With the growth of AP as a perceived standard of excellence and school quality, the incentive to use the AP name inappropriately also has increased. Some schools may label non-AP courses as AP, while others may sponsor AP courses without providing proper facilities and personnel resources.

Students can be affected adversely when preparatory courses are compressed or when students are allowed to skip prerequisite courses without first demonstrating mastery before taking an AP course. However, efforts to prepare students for advanced study often stimulate improvements in prerequisite courses; and this is to be strongly encouraged.

Advances in technology make it possible to create online AP courses and to provide other online support, such as professional development for AP and IB teachers. The potential for growth in this area is virtually unlimited, but so is the potential for problems if suitable quality controls are not established. For example, students who take an AP science course online and earn a qualifying score on the examination may earn college credit or placement without having had any advanced laboratory experience.

Decisions about awarding college credit or advanced placement for qualifying scores on AP and IB examinations are best made on an individual basis, using multiple sources of information. Decisions based on sampling average student performance in courses at typical colleges is not strong enough to infer that all, or even most, AP or IB students who earn a particular examination score are qualified for either credit or placement.

RECOMMENDATIONS

Recommendation 1: The Primary Goal of Advanced Study

The primary goal of advanced study in any discipline should be for students to achieve a deep conceptual understanding of the discipline's content and unifying concepts. Well-designed programs help students develop skills of inquiry, analysis, and problem solving so that they become superior learners. Accelerating students' exposure to college-level material, while appropriate as a component of some advanced study programs, is not by itself a sufficient goal.

Recommendation 2: Access and Equity

Schools and school districts must find ways to integrate advanced study with the rest of their program by means of a coherent plan extending from middle school through the last years of secondary school. Course options in grades 6–10 for which there are reduced academic expectations (i.e., those that leave students unprepared for further study in a discipline) should be eliminated from the curriculum. An exception might be made for courses designed to meet the needs of special education students.

Recommendation 3: Learning Principles

Programs of advanced study in science and mathematics must be made consistent with findings from recent research on how people learn. These findings include the role of students' prior knowledge and misconceptions in building a conceptual structure, the importance of student motivation and self-monitoring of learning (metacognition), and the substantial differences among learners.

Recommendation 4: Curriculum

Curricula for advanced study should emphasize depth of understanding over exhaustive coverage of content. They should focus on central organizing concepts and principles and the empirical information on which those concepts and principles are based. Because science and technology progress rapidly, frequent review of course content is essential.

Recommendation 5: Instruction

Instruction in advanced courses should engage students in inquiry by providing opportunities to experiment, analyze information critically, make conjectures and argue about their validity, and solve problems both individually and in groups. Instruction should recognize and take advantage of differences among learners by employing multiple representations of ideas and posing a variety of tasks.

Recommendation 6: Assessment

Teachers of advanced study courses should employ frequent formative assessment of student learning to guide instruction and monitor learning. External, end-of-course examinations have a different purpose: they certify mastery. Both types of assessment should include content and process dimensions of performance and evaluate depth of understanding, the primary goal of advanced study (see Recommendation 1).

Recommendation 7: Qualified Teachers and Professional Development

Schools and districts offering advanced study must provide frequent opportunities for continuing professional development so teachers can improve their knowledge of both content and pedagogy. National programs for advanced study should clearly specify and monitor the qualifications

expected of teachers. Professional development activities must be adequately funded and available to all teachers throughout their teaching careers.

Recommendation 8: Alternative Programs

Approaches to advanced study other than AP and IB should be developed and evaluated. Such alternatives can help increase access to advanced study for those not presently served and result in the emergence of novel and effective strategies.

Recommendation 9: The Secondary–College Interface

9(a): When awarding credit and advanced placement for courses beyond the introductory college level, institutions should base their decisions on an assessment of each student's understanding and capabilities, using multiple sources of information. National examination scores alone are generally insufficient for these purposes.

9(b): College and university scientists and mathematicians should modify their introductory courses along lines similar to those proposed in this report for high school advanced study. Departments should carefully advise undergraduates about the benefits and costs of bypassing introductory courses.

Recommendation 10: Changes in the AP and IB Programs

The following substantial changes in the AP and IB programs are recommended:

10(a): The College Board should abandon its practice of designing AP courses in most disciplines primarily to replicate typical introductory college courses.

10(b): The College Board and the IBO should evaluate their assessments to ensure that they measure the conceptual understanding and complex reasoning that should be the primary goal of advanced study. Programs of validity research should be an integral part of assessment design.

10(c): Both the College Board and the IBO should take more responsibility for ensuring the use of appropriate instructional approaches. Specifying the knowledge and skills that are important for beginning teachers and providing models for teacher development are likely to advance teacher effectiveness.

10(d): The College Board should exercise greater quality control over the AP trademark by articulating standards for what can be labeled an AP

course, desirable student preparation for each course, strategies for ensuring equity and access, and expectations for universal participation in the AP examinations by course participants. When necessary, the College Board should commission experts to assist with these tasks.³ These standards should apply whether AP is offered in schools or electronically.

10(e): The College Board and the IBO should provide assistance to schools in their efforts to offer high-quality advanced courses. To this end, the College Board should provide more detailed curriculum, information about best practices for instruction and classroom assessment, and strategies for enhancing professional development opportunities.

10(f): The College Board and the IBO should offer more guidance to educators, policymakers, and the general public concerning proper uses of their examination scores for admission, placement, and teacher evaluation. They should also actively discourage misuse of these scores.

10(g): The College Board and the IBO should develop programs of research on the implementation and effectiveness of their programs.

³The committee notes that the College Board has used this strategy in the past. For example, in 1997 the National Task Force on Minority High Achievement was convened to assist the College Board in outlining recommendations for substantially increasing the number of African American, Latino, and Native American undergraduates who achieve high levels of academic success.

Introduction

Excellence in science and mathematics education is a critical need and goal for the United States. Programs for advanced study, particularly the Advanced Placement (AP) and International Baccalaureate (IB) programs, are major contributors to science and mathematics education at the high school level. Large numbers of high school students seek access to these courses, and many colleges use them in their admission decisions. High school curricula are strongly affected by these programs, since schools often structure their courses in the middle-school and early high school years to facilitate participation in advanced study.

This report presents the results of a 2-year effort by a committee of the National Research Council (NRC) to examine programs for advanced study of U.S. high school mathematics and science (calculus, biology, chemistry, and physics). As part of the scope of the study, the NRC asked the committee to “. . . explore the current status of high school mathematics and science education by means of an in-depth look at programs designed for advanced students, such as the AP and IB programs.” The study focuses on AP and IB because these are the only advanced secondary science and mathematics programs of national scope. However, the availability of and participation in these programs are highly variable, with large differences among schools and their student populations.

The primary purpose of this report is to use the results of recent research on learning, curriculum, instruction, assessment, and professional development as lenses to examine educational programs for advanced secondary science and mathematics in the United States. We are now in a position to ask whether the AP, IB, and other programs of advanced study as currently implemented are as effective as possible, and how they might be improved.

BACKGROUND

The National Science Foundation and the U.S. Department of Education commissioned this study following the publication of a disappointing assessment of the performance of U.S. students in advanced mathematics and physics, which was part of the Third International Mathematics and Science Study (National Center for Education Statistics [NCES], 1998). This international comparison appeared to show that U.S. students of advanced mathematics and physics lagged behind their counterparts in other countries. However, a more recent study indicates that this pessimistic assessment may have been unwarranted because the original sampling included many students that should not have been classified as being in “advanced” courses. Indeed, a second administration of the test to U.S. students enrolled in AP calculus and AP physics showed that, in this sample, the AP calculus students performed better than those in all other countries, and the performance of the AP physics students was substantially above the mean of the other countries (Gonzalez, O’Connor, and Miles, 2001). One important lesson from these comparisons is that the percentage of U.S. students taking bona fide advanced courses is too small compared with other countries.

Although international comparisons served as a catalyst for this study, the need to undertake the study was clear for other reasons as well. Perhaps most important, a greatly improved understanding of the conditions for successful teaching and learning has emerged in recent years. These advances have been summarized in several NRC reports, including *How People Learn: Brain, Mind, Experience, and School* (Expanded Edition) (NRC, 2000b). The present analysis demonstrates that programs for advanced study are frequently inconsistent with the findings of this body of research on cognition and learning. We show how program developers can remedy this situation by considering all the components of educational programs when developing their courses: curriculum, instructional methods, ongoing (curriculum-embedded) and end-of-course (summative) assessments, and opportunities for teacher preparation and professional development.

Another factor contributing to the urgency of this study is the rapid growth of the AP and IB programs. In 2000, there were 433,430 AP exams taken in math and science, compared with only 164,333 in 1990 (College Entrance Examination Board [CEEB], 2000c),¹ and the number is expected to continue to grow rapidly in the future. The IB program had about 19,000 degree candidates in 2000, and roughly 13,000 IB exams were taken in the

¹The College Board, which oversees the AP program, does not keep track of who or how many students enroll in AP courses, but estimates that about 30–40 percent of students enrolled in a course do not take the exam. If that holds true for all courses, then 433,000 AP exams in science and mathematics translate to about 580,000 enrollments.

sciences and mathematics in the United States that year.² Clearly, these are no longer programs only for an elite audience; participation in some form of advanced study has become almost the norm for students seeking admission to the most selective colleges. Advanced study programs can affect students' future opportunities, and the quality and availability of these programs have become central concerns.

As the United States becomes more diverse, racial and socioeconomic gaps persist in high school students' access to and success in advanced study. While minority participation in advanced mathematics and science courses has increased substantially during the past 20 years (National Science Foundation [NSF], 1999), inner-city and rural schools, especially those with high percentages of minority and poor students, are still less likely to offer these courses (Ma and Willms, 1999). Many schools in low-income communities remain ill equipped to provide advanced study, in part because they are less likely than schools with greater resources to have highly qualified teachers or sufficient laboratories, equipment, and other curriculum materials (Darling-Hammond, 2000; Ferguson, 1991, 1998; Greenwald, Hedges, and Laine, 1996; Murnane, 1996; Wright, Horn, and Sanders, 1997). In addition to these gaps, there are parallel disparities in access within racially and ethnically diverse schools. In these schools, African American, Hispanic, and Native American students and those of low socioeconomic status are much less likely than white or Asian American students to enroll in upper-level mathematics and science courses even when such courses are available (Atanda, 1999; Horn, Nunez, and Bobbitt, 2000; Ma and Willms, 1999). Those who do enroll are much less likely to fare as well as white or Asian American students on national examinations. These facts represent a major challenge for advanced study programs.

A number of additional trends and concerns make this an appropriate time to analyze programs for advanced study of science and mathematics:

- *Changes in science and mathematics*—Rapid advances (e.g., the tremendous progress in molecular biology) mean that traditional course content may be inadequate for the future.
- *Demands for accountability*—There is increasing pressure from policymakers and the public for school accountability, and participation in advanced study is often used as a measure of school quality.
- *Connections to earlier years and higher education*—Since learning of science and mathematics tends to be hierarchical, advanced programs in

²These numbers are estimates based on IB Worldwide Statistics.

these subjects have major implications for the earlier years of schooling and vice versa. Similarly, as introductory college courses evolve and their emphases change (see, for example, NRC, 1999d), it is important to review the secondary courses that precede them.

- *Teacher shortages*—A teacher shortage of immense proportions is projected to emerge in the next few years in many districts. These shortages are likely to be particularly acute for science and mathematics (National Commission on Mathematics and Science Teaching for the 21st Century, 2000; NCES, 2000b). Teaching in advanced programs requires extensive knowledge of both subject matter content and pedagogical methods. Thus it is unclear how the staffing needed to implement and maintain the quality of these programs will be provided in the future. This problem is especially severe in schools with large populations of minority and poor students, where shortages of qualified science and mathematics teachers are already daunting (National Commission on Mathematics and Science Teaching in the 21st Century, 2000).

- *Economic forces*—The increasing demands of a knowledge-based economy add to the importance of providing advanced courses in mathematics and science for as many students as are motivated and prepared to enroll in them.

- *Information technology*—Advances in information technology are transforming work, teaching, and learning, creating new opportunities for instructional delivery. For example, distance learning is now being used to deliver advanced study programs to schools that have few resources, small student populations, or insufficient numbers of teachers to offer a program within the school.

- *Assessment*—Better understanding of the uses and impact of assessment with regard to classroom dynamics and student learning creates opportunities for fundamentally changing and improving programs of advanced study (see, for example, NRC, 2001a).

BRIEF OVERVIEW OF THE PROGRAMS

The AP program was launched in 1955 by the College Entrance Examination Board, commonly referred to as the College Board,³ to provide college-level courses for advanced high school students. The program currently consists of 35 courses in 19 subjects, including 11 courses in 7 science and mathematics subjects.⁴ An individual school can choose to offer any number

³The College Board is an independent, not-for-profit membership organization. Membership includes colleges, universities, and secondary schools.

⁴See <http://apcentral.collegeboard.com/courses/overviews/> (February 11, 2002).

and combination of these courses. The AP program is built around elective, end-of-course examinations that are graded on a five-point scale. The College Board produces content outlines for its courses, largely by surveying colleges and universities about the content of their introductory courses. The national AP examinations are used by many colleges and universities as a basis for granting credit or advanced placement to incoming students. Additional information about the AP program is provided in Chapter 3.

The IB program was developed in the late 1960s to provide an international standard of secondary education for a mobile population—primarily the children of diplomats and others stationed outside their home countries for extended periods. One goal was to prepare these students to qualify for university admission in their home countries after schooling abroad. As with the AP program, a final examination developed by the International Baccalaureate Organisation⁵ (IBO) is a major component of an assessment process that helps determine eligibility for university admission. The examination is supplemented by teacher-devised classroom assessments, such as a portfolio of laboratory reports. Schools cannot choose to offer individual IB courses; they must provide a program of interrelated courses that students seeking the IB diploma take during their junior and senior years. While some students take individual IB courses much as they would an honors course, approximately two-thirds are diploma candidates, taking a full program of six or seven courses over the 2-year period. A detailed course outline and specific goals are provided for the courses. Additional information about the IB program is provided in Chapter 4.

As a consequence of the growing belief that all students should have access to quality educational programs, many states and the federal government have advocated an expansion of programs such as AP. Former U.S. Department of Education Secretary Richard Riley called for at least one AP course in every school by 2002 and an additional course incorporated into a school's AP offerings each year for the remainder of the decade.⁶ While Governor of Texas, George W. Bush said, "Making Advanced Placement available to students across Texas is one of the best ways to challenge students academically" (Callahan, 2000, [from AP Program 1999, p. 16]). Many states have advisory councils and other structures in place specifically to promote and improve AP offerings.

The U.S. education system has changed dramatically since these programs were first established, and the programs and their assessments are now being used in ways that initially were neither anticipated nor intended. The leaders of these programs are aware of the need for reform. For ex-

⁵The IBO is a not-for-profit educational foundation based in Geneva, Switzerland.

⁶See www.ed.gov/Speeches/02-2000/20000211.html (February 11, 2002).

ample, in 2000 the College Board convened a Commission on the Future of the Advanced Placement Program, asking it to focus on ways of maintaining the integrity and quality of the program while improving equity of access to accommodate greater student diversity.⁷

WHAT IS ADVANCED STUDY?

The committee found that defining “advanced study” for secondary students is surprisingly difficult. Establishing a clear definition of advanced study is problematic in part because these programs share many of the objectives of other high school courses. For example, all courses in mathematics and science, whether “advanced” or not, should encourage students to think about concepts in addition to factual information. Similarly, all courses should engage students in scientific or mathematical reasoning.

A number of overlapping definitions are often used to characterize advanced study for high school students in the United States. Some have tended to equate advanced study with accelerated or college-level learning. However, the committee finds this definition insufficient because as discussed in detail later in this report, the inclusion of too much accelerated content can prevent students from realizing the important goal of attaining deep conceptual understanding.⁸

Furthermore, introductory courses at colleges and universities often do not take advantage of the greatly improved understanding of the conditions for successful teaching and learning mentioned earlier. As a result, they are not necessarily good models for emulation at the high school level. It is possible to enrich students’ learning beyond what is typically found in secondary curricula in other ways—for example, by adding depth or rigorous analysis, applications to new domains, or opportunities for investigation. Thinking of advanced study entirely in the context of obtaining college credit and placement is unnecessarily limiting.

For purposes of this report, therefore, the committee adopted a focus on helping students achieve deep conceptual understanding as the primary goal of advanced study. At the same time, committee recognizes that accelerated exposure to college-level content has an appropriate place in some pro-

⁷The sponsors of these programs have acknowledged and appreciate the importance of increased access for underserved students. However, it is probable that offering courses alone, without providing support systems for both students and teachers and appropriate prerequisite education in the earlier years, would prove unsuccessful. These issues are discussed at length in Chapter 2, this volume.

⁸Conceptual understanding involves the creation of rich integrated knowledge structures around an underlying concept. Understanding is not a static point in learning, but rather a continually developing mental activity.

grams, provided it is well integrated with the primary goal of nurturing conceptual understanding.

THE STUDENT CLIENTELE FOR ADVANCED STUDY

For whom are programs of advanced study appropriate? Again the answer is not straightforward. This study did not examine programs intended only for the most exceptional learners, who might constitute at most a few percent of the student population. Exceptional learners sometimes require opportunities that differ significantly from what is needed or effective for other able and well-motivated students; they may need earlier access to advanced material and a faster pace (see Annex 6-1).

While it is important to provide challenging opportunities for the most talented students, the primary concern of this study is with programs available to a broader group of highly motivated students with solid academic preparation. This population is limited at least in part by the adequacy of students' prior educational opportunities, the ability of their schools to provide effective learning environments, and the availability of qualified and effective teachers. It is the committee's consensus that improvements in these areas could enlarge significantly the group of students for whom advanced study programs such as AP and IB are a realistic choice. *Therefore, instead of asking, "For whom is advanced study appropriate?" we think it much more useful to ask, "How can high school science and mathematics education at both the introductory and advanced levels be improved so that a larger number of students will have access to advanced study and a realistic chance of succeeding once enrolled?"* Achieving this goal will require fundamental changes in curriculum, approaches to teaching and learning, assessment tools, and teacher preparation and professional development. Both school systems and institutions of higher education will have to change in significant ways.

The pathways leading to advanced study begin early. If a student has not developed a sound conceptual understanding of algebra, geometry, and functions, for example, he or she may be lost even in a well-taught calculus class. The committee envisions a future in which the conceptual understanding and habits of mind essential to advanced study are successfully nurtured among a greater number of students than at present. In this hoped-for future, early tracking of some students into academically weak courses is avoided so that each child has a suitable opportunity to develop and demonstrate his or her individual academic abilities and talents.

It should be noted that the early high school years are important as well for students who do not go on to advanced study. The programs reviewed

in this report have a profound influence on the course structure and course-taking patterns of all students throughout the high school years. Moreover, AP and IB teachers—who are often among the best in their schools—are a critical resource for the entire high school system.

STUDY CHARGE AND APPROACH

The charge to the committee was as follows:

... to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in U.S. high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

The committee was charged with answering the following questions:⁹

1. What does research tell us about the ways in which high school students learn science and mathematics?
2. To what extent do the AP and IB programs in mathematics and science incorporate current knowledge about cognition and learning in their curricula, instruction, and assessments?
3. To what extent do AP and IB programs encourage teaching approaches that are consistent with current research on effective instructional practices?
4. How do final assessments generally, and AP and IB assessments in particular, influence instructional practice?
5. What does research tell us about how teachers learn to teach, and about effective professional development opportunities?
6. What is the impact of student assessment on the learning process, and how could student assessment be used to improve student learning in advanced courses?
7. To what extent do the IB and AP programs reflect the best in current thinking about content and curriculum for teaching mathematics and science?
8. How can the goal of equitable and broad access to programs for advanced study best be pursued?

⁹The full text of the committee's statement of task can be found in Appendix C; only a subset of the questions to be addressed is presented here.

9. How does the interface with higher education affect programs for advanced study in secondary schools?

In approaching its charge, the committee considered research about how people learn and gain expertise in a discipline. The committee found surprisingly sparse empirical data about either the AP or IB programs. For example, systematic information is lacking about how the AP and IB programs are actually implemented in U.S. high schools. Systematic data about the AP and IB examinations are also scarce, as is information about the long-term effects of AP and IB participation on student learning and achievement. Because neither independent researchers nor the AP or IB programs have gathered and published much of the data the committee sought for this study, it was necessary to use instead available program materials and expert testimony from program officials and experienced AP and IB teachers. As this report notes throughout, more studies are sorely needed to address the many issues and questions raised herein.

The committee was composed of scientist-researchers, secondary teachers having considerable experience with both the AP and IB programs, scientists and educators with expertise in the preparation of teachers and in issues of access and equity, experts in the cognitive sciences, and educational leaders. (Biographical sketches of the committee members are provided in Appendix B.) The committee held seven 2- to 3-day meetings over a period of 2 years, convened several small-group meetings, and interacted extensively between meetings. Representatives of the AP and IB programs and experts on science learning met with the committee. Deans of admission and chairs of science and mathematics departments in a diverse group of colleges and universities were surveyed about their uses of AP scores. These surveys and their results are described in Chapters 2 and 10, this volume.

Given the differences among the four disciplines under the committee's charge, panels of experts in each of the disciplines were convened to advise the committee. Each panel included at least one representative from each of the following categories: an expert on pedagogy in the discipline, an accomplished university teacher-scholar, a secondary teacher involved in advanced programs, and an educational researcher with a strong base in the discipline. The panels met for two 2-day sessions during the summer of 2000. The charge to the panels, the set of questions they were asked to consider, and a summary of their findings are included in Appendix A. Each of the panel reports was submitted to a group of independent reviewers for analysis and improvement, using procedures identical to the review process for all NRC reports. The panels' analyses and recommendations were an important source for the information on which the analyses, conclusions, and

recommendations of this report are based. The names and institutional affiliations of the panel members are provided in the front matter of the report. To keep the size of this volume reasonable, only summaries of the panels' findings and recommendations are included in Appendix A; the full text of their reports is available online for reading or downloading.¹⁰

AUDIENCES FOR THE REPORT

This report is intended to be useful to a variety of audiences concerned with high school science and mathematics curricula in general and advanced study in particular. Those who determine the shape of advanced study programs should find many opportunities to improve their programs along the lines suggested in this report. High school teachers should be interested in the analysis, which they can use both to develop useful teaching ideas and to press for changes in their schools that will enhance advanced study opportunities and make the programs effective for more of their students. It is hoped that university faculty members will see the importance of interacting with their secondary school colleagues and of encouraging deep conceptual understanding among their students, especially those who might become teachers. It is also hoped that university administrators will better appreciate the influence of their policies regarding admission and credit or placement for advanced study on both high schools and their students. Middle school and elementary school teachers should attain a better understanding of what they can do to prepare their students for advanced study at a later time and, in so doing, to enhance academic opportunities for all students. The report should be of value as well to policymakers and administrators at both the K–12 and university levels, who have a vital role to play in promoting the practices that research has shown to be effective and in providing the resources their teachers need to make advanced study successful for larger numbers of students. Finally, this report is intended to assist parents in being informed advocates for educational quality in science and mathematics.

OVERVIEW AND STRUCTURE OF THE REPORT

Chapter 2 provides essential background for this report, including the policy context of advanced study, the roles of middle schools and high schools in preparing students for these programs, and problems related to the supply of qualified teachers. It also addresses issues of equity and access to advanced study programs, factors that affect the success of students who enroll in advanced study, and the interface of secondary advanced study

¹⁰At www.nap.edu/catalog/10129.html/.

with colleges and universities. Chapters 3 and 4 introduce the AP and IB programs in some detail, while Chapter 5 provides a brief overview of some alternative advanced study programs. Chapter 6 summarizes the results of research on human learning that are critical for the present analysis. Chapter 7 extends these findings to the design of curriculum, instruction, assessment, and professional development as they relate to advanced study.

The report next turns to a detailed analysis of programs for advanced study, an analysis that is influenced strongly by the panel reports in the four individual disciplines. Chapter 8 presents an analysis of the programs from the perspective of research on learning, while Chapter 9 considers them from the perspective of curriculum, instruction, assessment, and professional development of teachers. Chapter 10 examines appropriate and inappropriate uses of these programs and their assessments of students. Finally, Chapter 11 presents the committee's recommendations for change.

Context of Advanced Study

There are approximately 36,000¹ public and private high schools in the United States (National Center for Education Statistics [NCES], 2001a). As a result of the U.S. tradition of local control of education, these schools vary widely along many dimensions, such as size, availability of facilities and resources, student and teacher characteristics, staffing levels, teacher preparation and qualifications, and stated goals and missions. Public, private, and parochial schools set their own educational standards² and are accountable to different oversight agencies. They implement widely varying curricula and administer different assessments, which are selected by their districts' or states' boards of education or boards of trustees. Local school boards organize their schools and implement policies related to ability grouping, course offerings, and staffing patterns in ways that reflect their differing missions, educational goals, and local political concerns and priorities. Thus, "high school" in the United States must be understood as a diverse array of institutions in which students, even those attending the same school, may have vastly differing opportunities and experiences, depending on their course of study.

Students' school experiences and academic achievement are most affected by the overall culture and atmosphere of their school, the organization and content of their school curriculum, and the training and qualifications of the teaching force they encounter during the course of their educational career (NCES, 2000b). It has been consistently demonstrated that disparities among schools along these dimensions have a profound effect on students' abilities to prepare for and fully participate in advanced study opportunities.

¹This figure excludes special education, alternative, and other schools not classified by grade span.

²Public school standards are usually established by local boards of education, which follow policies established by state boards of education.

Advanced study does not exist in isolation. As advanced study programs are currently structured in the United States, they have wide-ranging effects on the curricula, teachers, and students in the schools where they are offered. In turn, they are affected by political, educational, and social contexts that shape their implementation in schools. This chapter reviews the policy context of advanced study (including its financing), its educational context (including student preparation for advanced study in both middle and high school and teacher preparation), disparities in opportunities for different groups of students to pursue and succeed in advanced study, and the connections between advanced study and higher education.

POLICY CONTEXT

Immediately following the release of *A Nation at Risk* by the National Commission on Excellence in Education (1983), intense public interest was generated in improving the achievement of U.S. secondary school students by reforming and restructuring U.S. high schools. Although most states and school districts have adopted the commission's recommendations for strengthening state and local high school graduation requirements,³ U.S. high schools still face intense criticism from those involved in higher education, policymakers, education reformers, and the public for continuing to graduate significant numbers of students who are neither well prepared for college nor able to enter the workplace with the technological and problem-solving skills demanded by the new economy (American Federation of Teachers [AFT], 1999; Kaufman, Bradby, and Teitelbaum, 2000; National Association of Secondary School Principals [NASSP], 1996; National Commission on the High School Senior Year [NCHSSY], 2001a, 2001b; Powell, Farrar, and Cohen, 1985; Sizer, 1992).

High schools may not be failing to the degree that some of these reports indicate (see for example, Berliner and Biddle, 1996). However, the Mathematics and Science Report Cards of the National Assessment of Educational Progress (NAEP)⁴ and data gathered from state education testing and the SAT I and II suggest that the schools are doing a less than stellar job in challenging all students to achieve at the same high levels.

In 1999 Richard Riley, then U.S. Secretary of Education, declared it was time to change U.S. high schools so they would be better aligned with the

³The Five New Basics recommended by the commission included 4 years of English; 3 years of mathematics; 3 years of science; 3 years of social studies; one-half year of computer science; and, for the college-bound, 2 years of foreign language.

⁴Available at <http://www.nces.ed.gov/nationsreportcard/> (February 10, 2002).

demands and needs of modern times.⁵ The needed changes, according to Riley, must include high expectations for all students, rigorous curricula, support for students who need help in meeting higher standards, an educational structure that is flexible in meeting students' needs, and well-prepared teachers who have adequate opportunities for professional development and the time to work together in achieving student and school goals. In light of all of the recent criticism leveled at high schools, many policymakers and educators have turned to AP⁶ and IB to improve their academic programs (see for example, The National Education Goals Panel, Promising Practices, Goal 3,⁷ and legislation in Virginia⁸ and California⁹). Rod Paige, current U.S. Secretary of Education, has continued the Department of Education's support for AP in 2001–2002 by providing \$6.5 million in grants to 18 states, the District of Columbia, and Guam so that thousands of students from low-income backgrounds can prepare for and take AP examinations.¹⁰ Several states also have adopted policies to support IB that are similar to those for AP.

In the view of many educators and policymakers, AP and IB complement the nation's decentralized system of educational governance and the different approaches that states and districts have adopted with regard to academic standards, curriculum, and instruction. That is, AP and IB are national programs that are controlled locally. Both programs provide a basic structure, quality standards, and nationally recognized external measures of student achievement, but states and individual schools can decide which students are able to take the courses, who is qualified to teach them, and how the courses will be taught.

At least 26 states provide legislative support to AP programs in their schools by subsidizing examination fees or costs for teacher education, pro-

⁵Riley, 1999, available at www.ed.gov/Speeches/09-1999/990915.html (February 11, 2002).

⁶Secretary Riley called on all schools to add one AP course to their curricular offerings for each of the next 10 years (ending in 2010) so that every student in every high school in the United States could have access to at least ten AP courses. The Federal AP Incentive Act (1999) provided funds to help low-income students pay the fees for AP examinations.

⁷The National Education Goals Panel uses an increase in the number of AP examinations receiving a grade of 3 or higher per 1,000 students in grades 11 and 12 to recognize schools with promising practices (<http://www.negp.gov> [February 11, 2002]).

⁸Virginia's Board of Education established an accountability system that requires every school division in the Commonwealth to offer at least two AP courses (www.pen.k12.va.us [February 11, 2002]).

⁹Spending \$20.5 million to make at least one AP class available for every high school student by the fall of 2000, although at first this might mean the students' going to a different location or watching the class on closed-circuit television (http://www.cisco.com/warp/public/779/govaffs/people/issues/educational_reform.html [November 26, 2001]).

¹⁰Additional information about this support is available at <http://www.ed.gov/PressReleases/10-2001/10012001b.html> (October 26, 2001).

viding funds for materials and supplies for AP courses, offering incentives for initiating AP courses or hosting training sessions, encouraging or mandating publicly funded colleges and universities to accept AP credit, and/or supporting professional development opportunities. State policies related to IB are less well established.¹¹

For many years, policymakers have focused on making advanced-level courses available to all students who are interested in participating. That goal has not yet been accomplished, but educators and policymakers have increased their efforts to provide many more students with equitable opportunities to learn and succeed in these courses. As discussed later in this chapter, the success of these efforts will depend on whether educational leaders assign top priority to increasing the number of underrepresented minority students who both are enrolled in advanced study and achieve at high levels.

The Role and Influence of Standards and Accountability

Reform is an ongoing and recurring theme in American education. The latest wave of educational reform, highlighted by calls for standards and accountability, began a little more than a decade ago. These efforts, which have garnered the broad-based support of education policymakers, business leaders, many educators, and the public, rest on three basic tenets: (1) all students should be held to the same high standards for learning; (2) high standards should serve as a basis for systems of assessment that can be used for the purpose of accountability; and (3) consequences should be imposed on schools, teachers, and sometimes students when students do not meet the established standards (Linn, 2000).

In the early 1990s, attempts at developing national standards for several subject areas met with varying degrees of success. The American Association for the Advancement of Science (AAAS) published *Benchmarks for Science Literacy* (1993), which contains science content standards based on a previous publication, *Science for All Americans* (AAAS, 1989). These publications outlined what the citizens of the United States should know about science. In 1996, the National Research Council (NRC) published the *National Science Education Standards* (NSES), a consensus document based on input from hundreds of scientists, science educators, and professional societies. The NSES relate to science content, teaching, teacher development, assessment, and the infrastructure required to support effective science education.

¹¹The committee noted that Florida has instituted a state scholarship program that allows Florida students who graduate with an IB diploma to attend any state university for free. California recently enacted legislation that grants sophomore standing in college to students who earn an IB diploma in high school.

Both documents call for fundamentally different approaches to teaching and learning science for students in grades K–12, with emphasis on inquiry and in-depth study of fewer topics than was characteristic of most science education programs at the time.

In mathematics, the National Council of Teachers of Mathematics (NCTM) has taken the lead in developing content standards for grades K–12 (NCTM, 1989, 2000). Like their counterparts in science, the national mathematics standards emphasize teaching and learning concepts and helping students understand mathematics much more deeply. Both the national science and mathematics standards leave decisions about specific curriculum to the discretion of the teacher, school, or district.

Based in part on these efforts, during the past decade 49 states and the District of Columbia have established statewide academic standards for what students should know and be able to do in at least some subjects; many states also have developed curriculum frameworks to support their standards. All 50 states currently test how well their students are learning, and 27 states hold schools accountable for results (*Education Week*, 2001).

This expectation for academic standards and measuring of student achievement has again assumed national prominence with the passage in January 2002 of the *No Child Left Behind* Act, which requires all states to test children in reading and mathematics every year while they are in grades 3–8. National expectations for assessing science achievement will begin in the 2007–2008 school year. Schools will be held accountable for the results.

The question now, after a decade of standards-based reform, is whether this approach achieves the results envisioned by policymakers and educators. Some contend that the assessments being used to measure achievement are narrowing the curriculum and discouraging high-quality instructional practices. These critics contend that greater gains in learning would occur if policymakers and educational decision makers focused more on equity in educational funding, teacher quality, and professional development, and less on testing. Supporters of standards-based reform point out that test scores are on the rise in a number of districts, including those that have shown low achievement in the past, and that a focus on accountability has forced teachers and schools to attend to the learning and achievement of all students, not just those at the top.

The AP and IB programs complement standards-based reform efforts at the advanced level. Both programs provide content-rich curricula and nationally recognized external measures of student achievement, but can be implemented by states and individual schools in ways that conform to local standards and link with other curricular offerings.

Financing Advanced Study Programs at the Local Level

Implementing, expanding, and supporting high-quality advanced study programs in science and mathematics requires resources that some school districts have difficulty providing. Such is the case particularly in rural areas and urban school districts that are supported by a limited property tax base and serve a large number of high-poverty or minority students. There is substantial variation in available fiscal resources across states, as well as among districts within states. For example, Rubenstein (1998) found that within some districts, schools with higher levels of student poverty sometimes receive lower allocations of both money and other educational resources than more affluent schools within the same district.¹²

Establishing and supporting high-quality advanced study programs also means that school districts must allocate sufficient resources for teacher professional development, instructional resources, and adequate student preparation at the middle school level. Indeed, disparities in school funding can exacerbate the already low level of access to advanced study courses for students who reside in high-poverty localities. Some states, such as Indiana, South Carolina, California, and Texas, have implemented state funding initiatives to ensure that advanced study opportunities will be equitably distributed across all of the states' schools and school districts.

Teacher Qualifications, Certification, and Challenges

In the quest for greater student achievement, state governments have undertaken reforms that have as their goal better teaching and learning for all students (Council of Chief State School Officers [CCSSO], 1998). Despite these reforms and the hard work of school and school district personnel, gaps still exist between desired and actual student achievement. These gaps can be attributed largely to disparities in the qualifications and distribution of the teacher workforce (Darling-Hammond, 2000).

Teaching quality matters. Numerous studies of the effects of teachers on student achievement have revealed that the availability and effectiveness of qualified teachers are strong contributors to observed variances in student learning (Jordan, Mendro, and Weerasinghe, 1997; Sanders and Rivers, 1996; Wright, Horn, and Sanders, 1997). There is broad consensus that students learn more from teachers with strong academic skills than from those with

¹²Two reports by the NRC's Committee on Education Finance (NRC, 1999a, 1999c) examine the link between school finance and student achievement and educational attainment. Readers interested in issues of school finance as they relate to student achievement are encouraged to review these reports.

weaker academic skills (see for example, Ballou, 1996; Ferguson and Ladd, 1996; Hanushek, 1996). Further, the effects of teachers on student learning appear to be additive and cumulative, and affected students may not be able to compensate for being taught by an unqualified teacher (NCES, 2000b). Results of a recent survey of secondary school teachers, students, school administrators, and parents also indicate that students who experience top-quality teaching are more likely than those who experience poor teaching to have high expectations for their futures (Markow, Fauth, and Gravitch, 2001).

Data drawn from the Fast Response Survey System (as cited in NCES, 2000b) show that the highest-poverty schools and those with the greatest concentrations of minority students have nearly twice the proportion of inexperienced teachers as schools with the lowest poverty levels and concentrations of minority students (20 versus 11 percent). Also troubling are studies showing evidence of strong bias in the assignment of students to teachers of different levels of effectiveness (Jordan et al., 1997). For example, African American students are nearly twice as likely to be assigned to the most ineffective teachers and half as likely to be assigned to the most effective teachers as white or Asian students (Sanders and Rivers, 1996). It also should be noted that new teachers, who increasingly are expected to have credentials in specific subject areas, leave high-poverty schools at a rate far greater than teachers in affluent suburban schools (NCES, 2000b).

High turnover rates and inexperienced teachers not only have an effect on student learning, but also deprive new teachers of mentors. A high proportion of experienced colleagues in a school can provide strong resources for advice and guidance to new teachers, as well as offer opportunities for experienced teachers to discuss their practices and learn from the experiences of others.

Darling-Hammond, Wise, and Klein (1999) discuss what is required of teachers if the gap in student achievement is to be closed and the goals of reform are to be met:

The new mission for education requires substantially more knowledge and radically different skills for teachers In order to create bridges between common, challenging curriculum goals and individual learners' experiences and needs, teachers must understand cognition and the many different pathways to learning. They must understand child development and pedagogy as well as the structure of subject areas and a variety of alternatives for assessing learning . . . teachers must be prepared to address the substantial diversity in the experience children bring with them to school—the wide range of languages, cultures, exceptionalities, learning styles, talents and intelligences that in turn [require] an equally rich and varied repertoire of teaching strategies. (p. 2)

Teacher Certification

All 50 states and the District of Columbia require public school teachers to be licensed. Requirements for regular licenses vary by state. However, all states require a bachelor's degree with a minimum grade point average, completion of an approved teacher-training program with a prescribed number of subject and education credits, and supervised practice teaching. One-third of the states currently require training in the use of information technology as part of the teacher certification process. Other states require teachers to obtain a master's degree in education, which involves at least a year of additional coursework after earning a bachelor's degree with a major in a subject other than education.

Many states offer alternative teacher licensure programs for those who have a bachelor's degree in the subject they will teach, but lack the education courses required for a regular license. Such programs were originally designed to ease teacher shortages in certain subjects, such as mathematics and science. Under other programs, states may issue emergency licenses to individuals who do not meet requirements for a regular license when schools cannot attract enough qualified teachers to fill positions. No states require special licensing for advanced study teachers. Further, the committee did not identify any colleges or universities that currently offer teacher preparation programs specifically designed for prospective teachers of advanced study.¹³

Teacher Shortages

Impending teacher shortages and the concomitant need to educate and retain more qualified teachers to staff the nation's schools have been predominant legislative and policy themes. Recently, some education policy experts have stated that the problem is more the distribution of qualified teachers than a teacher shortage. For example, these experts say that while there is a teacher shortage in secondary and middle schools, there is no such shortage in elementary schools; while there is a strong need for more single-subject teachers, especially in mathematics, physical science, special education, and bilingual education, there is no shortage of multisubject teachers or teachers of English or social studies; and while fast-growing cities in the South and dense urban areas will have a need for more teachers, suburban and more affluent schools will experience few shortages (Bureau of Labor Statistics, 1999; Eubanks, 1996; Ingersoll, 1999).

¹³According to *Education Week* (2001), the College Board is experimenting with developing a three-credit course colleges can offer to prospective AP teachers.

TABLE 2-1 Trends in Teacher Salaries Compared with Average Annual Salaries of Selected White-Collar Occupations, 1999

Teacher	Accountant III	Buyer/Contract Specialist III	Attorney III	Computer Systems Analyst III	Engineer IV	Full Prof. Public Doctoral	Assistant Prof. Public Comprehensive
\$40,574	\$49,257	\$57,392	\$69,104	\$66,782	\$68,294	\$78,830	\$41,940

SOURCE: Adapted from <http://www.aft.org/research/survey99/tables/tableII-5.html> (January 29, 2002).

The committee takes the position that qualified teachers are the backbone of both high-quality advanced study programs and the gateway courses leading to advanced study. Consequently, teacher shortages in mathematics and science and the dearth of teachers willing to teach in high-poverty and rural areas have implications for both access to and the quantity and the quality of advanced study programs available to students across the country. Education policy experts agree with this appraisal and suggest that government agencies, colleges and universities, and school districts initiate and support efforts to attract and retain qualified teachers in specific subjects and for particular geographic regions (National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Commission on Teaching and America's Future [NCTAF], 1996; NRC, 2000a).

Attracting the number of new teachers needed to the profession and retaining current teachers is a major challenge for the nation. In addition, given the challenges teachers face in the classroom (as discussed later in this chapter), the United States has not been willing to compensate teachers at levels comparable to those of people in other professions with similar levels of education, training, and expertise. The AFT reports that beginning teachers with a bachelor's degree earned an average of \$25,700 in the 1997–1998 school year; those with a master's degree earned slightly more. The estimated average salary of all public elementary and secondary school teachers during the 1998–1999 school year was \$40,574 (AFT, 2001). This salary is considerably less than that earned by other white-collar professionals (see Table 2-1).

EDUCATIONAL CONTEXT

Preparing for Advanced Study: Middle Schools

Academic preparation for advanced study begins in middle school. However, middle schools face a number of factors that compromise their ability to impart to as many students as possible the desire and preparation necessary to aspire to advanced study.

Educators, policymakers, and researchers have recently begun to focus considerable attention on middle-level education because of several widely held concerns. Specific concerns include a lack of focus on core academic courses; teachers without the appropriate training to teach young adolescents, especially those with special needs who are placed in general classrooms; appropriate approaches to teaching challenging academic material to students in this age group; and a much greater emphasis than in primary schools on ability grouping, which restricts high-poverty and minority students' access to challenging curricula and high-quality instruction and effectively precludes many of these students from participating in advanced study in high school (NCES, 2000a).

Middle School Mathematics and Science

The mathematics and science curricula for middle school students vary widely both within and among states (CCSSO, 1999). In mathematics, two-thirds of the states report that fewer than half of their students are in the traditional grade 8 mathematics curriculum by the time they reach that grade; the majority are enrolled in algebra-based mathematics (CCSSO, 1999). States are moving toward providing eighth-grade students with greater exposure to algebra topics, whether in full-fledged Algebra I or in pre-algebra courses. However, McKnight et al. (1987), Porter, Kirst, Osthoff, Smithson, and Schneider (1993), and Shaughnessy (1998) all found that the course titles provide only a rough indication of the content students actually receive.

In science, most seventh-grade students are studying life sciences or a biology-based curriculum, while most eighth-grade students are focusing on a mix of earth science and physical science (Schmidt, McKnight, Cogan, Jakewerth, and Hourang, 1999). CCSSO reports that a growing proportion of middle schools are instituting integrated or coordinated science programs. Integrated science programs, which intentionally blur the disciplinary lines among biology, chemistry, earth science, and physics, treat science as an integrated whole, based on the position that science learning during the middle school years should not be separated by discipline. Coordinated science curricula treat the disciplines of biology, chemistry, physics, and earth science individually, for perhaps 9 weeks each, and focus on the overarching ideas in science that can be studied in terms of each discipline rather than focusing on facts and details, as is more typical of traditional courses in these subjects. Finding qualified instructors for integrated and coordinated middle school science courses is often difficult because many science teachers at this level have not been prepared adequately in even one area of science.

Schmidt, Finch, and Faulkner (1992) analyzed a random sample of eighth-grade state curriculum guides in mathematics and science and concluded

that the curricula lacked focus, covered too many topics, were repetitious from grade to grade, and were implemented inconsistently across schools and classrooms, resulting in highly uneven exposure to a range of important curricular topics. This lack of rigor and coherence can have enduring long-term consequences for students, whether or not they decide to pursue advanced study later in high school.

If middle school is one of the gateways to advanced study (the other being introductory high school courses), it stands to reason that middle school and high school mathematics and science teachers should have structured opportunities to plan together and make decisions about the content and focus of the science and mathematics curricula for grades 7–12. However, a majority of high school teachers never interact with their peers from elementary and middle schools on the crucial issue of curricular alignment.¹⁴ Fewer than 30 percent of middle school teachers report having had any contact with high school teachers in their discipline with regard to curriculum structure, content, or design (NCHSSY, 2001a, p.16).

Even where school districts encourage and facilitate such vertical integration, however, their efforts can be compromised by the fact that today's students are far more mobile than ever before. The transience of the U.S. population will continue to confound efforts to provide well-defined academic pathways through the various grade levels that would enable more students to take advantage of advanced studies in high school.

Challenges of Middle School Teaching

A great deal of research conducted over the past 15 years has led to the conclusion that “in-field” teachers (those holding certification in the subject area to which they are assigned) not only know more content than their “out-of-field” colleagues, but also are better able to communicate that knowledge to students in their classrooms (Darling-Hammond, 2000). However, mathematics and science teachers in middle schools are far more likely to be teaching mathematics or science classes without certification in the subject area as compared with high school teachers (NCES, 2000b). This lack of certification in specific subjects can have profound effects on preparing middle school students for higher-level or advanced work in high school.

¹⁴Through its Vertical Teams Initiative, the College Board provides a vehicle for cross-grade contact (see Chapter 3, this volume). In the Vertical Teams approach, teachers from the middle school level up through AP work with one another to ensure that students are prepared to participate successfully at the advanced level by aligning curricula and developing content-specific teaching strategies.

Ability Grouping in Mathematics

Schmidt et al. (1999) note that 82 percent of 13-year-olds in the United States are in schools offering two or more differently titled mathematics classes for students at the same grade level, each with different expectations for student learning. These students from different middle-grade courses sometimes funnel into the same high school courses, leading to a lack of continuity in their mathematics education. Of even greater concern is that this early mathematics placement contributes to sorting students into different “pipelines,” some of which lead away from rigorous academic courses and programs. As noted below in the discussion of disparities in opportunities to pursue and succeed in advanced study, this problem is compounded for minority students and those of low socioeconomic status.

Early ability grouping at the middle school level has the most pronounced effect in mathematics because of the cumulative and sequential nature of the curriculum. Once students are placed in a mathematics sequence, it is very difficult for them to move to a more advanced sequence without doubling up (taking two mathematics courses during the same year) or attending summer school for an intensive and fast-paced version of a typical yearlong course. Summer school courses, because they are compressed, often do not provide a solid foundation of understanding for further study (see the report of the mathematics panel).

Several recent reports indicate that the process of determining which students will take advanced courses in high school begins with their placement in the first algebra course (Gamoran, 1987; Horn, Nunez, and Bobbitt, 2000; NCHSSY, 2001a).¹⁵ Once considered a ninth-grade course, algebra is becoming an eighth-grade option in increasing numbers of school districts,¹⁶ and some districts offer it to a small number of seventh graders.¹⁷

Placement in algebra is based most often on the results of standardized tests, teacher recommendations, and parental requests. It is not uncommon, however, for parental requests to take precedence over test scores. Studies have shown that, although counselors and school administrators use test scores or current mathematics placement to bar low-income students from high-level courses, they permit middle-class students with similar qualifications to enroll when parents intervene on their children’s behalf (Orfield and

¹⁵Some research indicates that ability grouping begins much earlier than middle school, perhaps even as early as elementary school.

¹⁶In 1998, 18 percent of U.S. eighth-graders were enrolled in Algebra 1.

¹⁷This shift is beginning to place great strain on middle schools, as well as many of the teachers in those schools who may not have received appropriate preparation or professional development for teaching this subject well to younger students (NRC, 1998, 2000a).

Paul, 1995; Paul, 1995; Romo and Falbo, 1996), even though parents sometimes push for class options for which their children may not be prepared or ready.

While mathematics is often the subject in which students initially are separated by perceived ability, this division occurs throughout the curriculum. Because this system of matching students to courses begins even before high school, many low-income and minority students (as well as other students who have been inappropriately accelerated) enter high school unprepared for demanding science and mathematics courses.

During the last two decades, attempts have been made to dismantle formal “tracking” systems for students. Few principals today would admit to tracking in their schools. However, the differentiation of students by ability that tracking was intended to address persists in the form of nonacademic courses and varying levels of specific academic courses (such as Algebra 1, Honors Algebra 1, Algebra 1: Parts 1 and 2, Basic Algebra, Introduction to Algebra, Business Algebra [Lucas, 1999; Powell et al., 1985]), coupled with allowing students to choose which course or series of courses to take.

Preparing for Advanced Study: High School

Curriculum

The curriculum of most high schools is organized around subject areas: English, mathematics, science, social studies, and fine and performing arts. Typically, academic courses are offered at multiple levels of difficulty, and students are grouped for instruction on the basis of earlier performance, perceived ability, student persistence, or parental request. In most comprehensive high schools, there are fairly distinct curricula for those who are college bound and those who are not. Even among those headed for college, decisions are made continually about whether a particular student should take the more rigorous AP and honors courses or the traditional academic versions of those courses. These different “college preparatory” classes are often characterized by different grading scales¹⁸ and degrees of depth. Many

¹⁸In some schools, the four-point grade-point average (GPA) system has been replaced by a weighted system. In a weighted system, final letter grades earned in honors or advanced courses are assigned a higher number of points to be used in the calculation of GPAs. For instance, using a four-point system, A = 4, B = 3, C = 2, and D = 1, whereas in one type of weighted system, A = 4.5, B = 3.5, C = 2.5, and D = 1.5. Thus, grades earned in honors or advanced courses help increase students' GPAs. Weighted grades were first devised to entice students to take more-rigorous classes without fear of hurting their class rank or GPA. Some colleges and universities readjust these weighted GPAs to their own systems when making decisions about which students to admit. There are many variations on this formula. Schools often devise a system that reflects their unique beliefs and goals.

students describe these alternative pathways as differing in tone and purpose, with the higher-level classes drawing more serious students who are more likely to stay on task (NCHSSY, 2001a; Office of Educational Research and Improvement [OERI], 1999).

Most comprehensive U.S. high schools offer a vast array of courses, and students are allowed to choose freely among them. This diversification and differentiation of curriculum is intended to address the differing abilities, interests, and preparation of the student body. However, diversification and freedom of choice also allow many students to choose poorly and consequently to leave school underprepared for either college or work (AFT, 2001; Frome, 2001; NCHSSY, 2001a).¹⁹ More-rigorous state high school graduation requirements have helped address these concerns, but the continuing availability of many low-level academic courses and their effects on students' course-taking patterns and achievement remain a significant problem for students, schools, higher education, and prospective employers.

While most high schools organize their curriculum as described above, others take a different approach, offering a core curriculum. Such a set of course offerings is quite narrowly focused and composed mainly of academic courses, and the students have very few choices among them. Electives are typically academically oriented courses. A student is more likely to take academic courses if he or she is assigned to them, if enrolling in such courses is considered the norm among students at a school, or if there are few (or no) undemanding courses available. This core curriculum approach is one way schools might try to address disparities in course-taking patterns among students; research on other promising practices is greatly needed.

Lee and colleagues have evaluated the relative efficacy of the above alternative curriculum structures, defined as "differentiated" and "constrained," respectively, in both public and Catholic schools (Lee, 2001; Lee, Burkam, Chow-Hoy, Smerdon, and Gevert, 1998; Lee, Croninger, and Smith, 1997).²⁰ Using two different nationally representative longitudinal datasets and multilevel analysis methods, they evaluated the effects of curriculum structure and other student- and school-related variables on two outcomes: (1) learning in mathematics during the high school years and (2) distribution of learning in a school according to students' social class. The studies demonstrated that

¹⁹Although almost 70 percent of high school graduates now go on to college, only about 28 percent of them complete a bachelor's degree, and only 8 percent complete an associate's degree by the time they reach age 28 (NCES, 2001a). Of the high school graduates who go to college, approximately 30 percent need to take a remedial course in basic subjects such as English and algebra before they can begin college coursework (Kirst, 2000).

²⁰The constrained curriculum model is more common in Catholic than in public schools in the United States (Bryk, Lee, and Holland, 1993; Lee, 2001; Lee and Bryk, 1989).

the constrained curriculum was both more effective (i.e., it induced higher levels of learning among all students in the school) and more equitable (i.e., socioeconomic status was less strongly correlated with learning in schools with a constrained curriculum). Indeed, holding all students to the same high standards and eliminating low-level academic courses is recommended by many organizations, including the NASSP (1996), the Southern Regional Education Board (Bottoms, 1998; Kaufman et al., 2000), the AFT (2000), the NCHSSY (2001a, 2001b), and the American Youth Policy Forum (2000).

A constrained curriculum does not imply an absence of differentiation among students. Rather, differentiation in constrained curricula is related to the pace at which students progress through the curriculum, not the content of the courses. As a result, some students may graduate from high school having completed calculus, while others may take longer to master algebra or geometry and graduate having completed only Algebra II. It is important to reiterate that both the path and the content of the courses along the path are the same, or nearly so, for all students, regardless of their future educational plans or perceived abilities (an exception might be made for classes designed to meet the needs of special education students). What differs is the time and support students need to move along the path and how far they progress. To be successful, some students will require additional academic support, such as “double dosing” (taking the same course over more than one class period). Such students may have to skip some other activity in their school day to do so, but after-school and Saturday academic classes, tutoring, and summer “bridge” classes can help them develop academic competencies (e.g., analytic reading and writing) or give them a head start on the curriculum they will be expected to learn should they pursue advanced coursework. The idea is that remediation is reduced as students demonstrate greater learning and achievement. Additionally, some school districts, understanding that students differ in the amount of time they may need to complete high school graduation requirements when expectations are high, have opted to allow their students to complete high school in 3, 4, or 5 years in accordance with individual achievement and educational needs (see, e.g., Johnston, 2000). This flexibility is consistent with recommendations made by the American Youth Policy Forum (2000).

High School Mathematics and Science

Many states have set 3 years of high school mathematics as a requirement for high school graduation, following the recommendation of the National Commission on Excellence in Education (1983) (*Education Week*, 2000). Research on patterns of student achievement in mathematics and science demonstrates that the amount of time spent in instruction and the number

TABLE 2-2 Percentage of All High School Students Taking Higher-Level Mathematics Courses by Graduation, 1998 and Change 1990 to 1998

Geometry or Integrated Mathematics 2		Algebra 2 or Integrated Mathematics 3		Trigonometry or Precalculus		Calculus or AP Calculus	
1998	% Change 1990 to 1998	1998	% Change 1990 to 1998	1998	% Change 1990 to 1998	1998	% Change 1990 to 1998
72%	+11%	63%	+14%	39%	+10%	12%	+3%

SOURCE: Adapted from CCSSO (1999).

and level of courses taken are strongly related to achievement (Adelman, 1999; Jones, Davenport, Bryson, Bekhuis, and Zwick, 1986; Jones, Mullis, Raizen, Weiss, and Weston, 1992).

The typical progression of courses in high school mathematics leading to calculus begins with Algebra I and is followed (although not always in this order) by geometry, Algebra II, trigonometry, analysis or precalculus, and calculus.²¹ Table 2-2 indicates the number of students taking higher-level mathematics classes in 1998 and the changes in the percentage of students doing so between 1990 and 1998.

National consensus standards for mathematics and science have been available for the past decade (American Association for the Advancement of Science [AAAS], 1993; NCTM, 1989, 2000; NRC, 1996) and frequently have served to guide individual states in developing their own standards, curriculum frameworks, and assessments to improve learning in these subjects. In many states, however, standards in mathematics and science have been developed in the context of local political considerations and needs rather than with an eye to regional or national cooperation and consensus, or remain enmeshed in debates about the appropriate ways in which students should learn these subjects. Thus, expectations for what students should know and be able to do vary greatly among states (Gandal, 1997).

It should be noted that instructional time and course taking in mathematics and science vary widely among U.S. schools. Such variation relates to ability (Benbow and Stanley, 1982; Benbow and Minor, 1986), but also is correlated with students' socioeconomic status (Goodlad, 1984; Horn, Hafner, and Owings, 1992; Lee, Bryk, and Smith, 1993; McKnight et al., 1987; Oakes, 1990). While the data reported in Table 2-2 for mathematics and in Table 2-3 for science do not reveal differences in course taking among students of different racial and ethnic groups, such is the case primarily because many

²¹There are numerous remedial and basic mathematics courses below Algebra I, and some 10 percent of public high school graduates in 1998 never progressed beyond them (NCES, 1998).

TABLE 2-3 Percentage of All High School Students Taking Higher-Level Science Courses by Graduation, 1998 and Change 1990 to 1998

Biology		Chemistry		Physics	
1998	% Change 1990 to 1998	1998	% Change 1990 to 1998	1998	% Change 1990 to 1998
92%	-3	54%	+9%	24%	+4%

SOURCE: Adapted from CCSSO (1999).

states do not report data in this fashion. Of the 13 states that do report mathematics enrollment by race/ethnicity, enrollment of African American and Hispanic students in higher-level mathematics courses lagged behind that of whites and Asians in the same courses in all cases.

Most state high school graduation requirements include the completion of at least 2 years of science (*Education Week*, 2000), although college-bound students traditionally take more. These students usually take science in the sequence of biology, chemistry, and physics, with some taking earth science before biology. Physics is the least frequently selected science, often because most students have completed their graduation requirements in science by the junior year.

Table 2-3 indicates the number of high school students who had taken a specific science course by the time they graduated in 1998 and the changes in the percentages of students in those courses between 1990 and 1998. Although the increases in enrollment in upper-level science courses are not as dramatic as those for higher-level courses in mathematics, Table 2-3 indicates that more students now enroll in chemistry and physics. Recently, there has been an effort to change the order in which science courses are taught, with physics serving as the introduction to the science course sequence (Roy, 2001). Should this effort gain momentum, the numbers of students who graduate with a credit in physics could rise dramatically during the next decade.

Several states have recently implemented integrated or coordinated science programs for ninth- or ninth- and tenth-grade students. Students leaving an integrated or coordinated science program often go on to more specialized or advanced science courses during their last 2 years of high school (CCSSO, 1999). This move toward integrating science during the first 2 years also may account for the small decrease in the number of students who have taken biology, since that course is typically offered to ninth or tenth graders.

Challenges of High School Teaching

There are approximately 1.4 million teachers of grades 9–12. These secondary school teachers see themselves primarily as subject area specialists.

In general, high school teachers are members of subject-based departments that operate quasi-independently within a high school. Most academic departments are directed by department chairs, who make decisions about curriculum, instructional materials, textbooks, and teaching assignments.

Secondary school teachers typically are responsible for five periods of instruction per day.²² Teaching responsibilities for high school teachers generally exceed 100 students and in some districts reach nearly 175 students. With such high enrollments, it is difficult for many high school teachers to know their students well or to adjust pedagogy to meet individual students' needs, particularly when there are special needs. Within the average school day, most high school teachers have 13 minutes of instructional planning time for every assigned teaching hour, and consequently have little opportunity to work with colleagues on curricular or instructional planning (Darling-Hammond, 1999b; NCTAF, 1996).

In a study of teachers' work, Louis (1992, p. 150) reports that what matters most to secondary school teachers is time. To be effective, teachers need time to remain abreast of changes in their subject areas and in the pedagogy related to their disciplines. They need time to plan effectively and collaboratively, to receive and analyze feedback about their teaching, and to reflect on their own teaching practice. However, many high school teachers report that they have little time during the school day to interact with other teachers (Choy et al., 1993, p. 128).

The National Institute on Student Achievement, Curriculum, and Assessment (OERI, 1999) describes two different teacher approaches to dealing with the lack of time for activities besides teaching. Some teachers indicate that they do what they can during school hours; what is not finished during the school day remains uncompleted. Others extend their working hours far beyond contract time to allow for collaboration and planning with other teachers, for grading, or for preparing for their own classes. In urban schools, teachers may not be able to remain in their buildings after hours because of safety concerns, making it even more difficult for any collaborative planning or collegial interactions to take place.

Secondary school teachers are more likely than teachers at other levels to report feeling isolated and unsupported (Bureau of Labor Statistics, 1999; NCES, 2000b; OERI, 1999). They also report that there are many competing demands on their own and their students' time that interfere with instruction. High school teachers who leave the profession frequently cite as their major reasons for doing so concerns about inadequate support from their school's administration; nonacademic demands, such as cafeteria duty; poor student motivation to learn; and student discipline problems (National Sci-

²²This varies in schools that use alternative scheduling options.

ence Teachers Association [NSTA], 2000). Isolation is an especially frequent complaint of advanced study teachers, who are often the only members of their departments assigned to teach particular classes, such as AP physics or IB chemistry. Efforts to combat this isolation have led both the College Board and the International Baccalaureate Organisation (IBO) to establish online teacher education and support networks.

Students

The U.S. Department of Education (NCES, 2001a) estimates that there will be more than 15 million students in grades 9–12 in public and private high schools in the United States in the fall of 2002 and an additional 235,000 home-schooled students in these grade equivalents (Parent Survey of the National Household Education Surveys Program, as cited in Basham, 2001). The majority of secondary school students say that seeing friends is the most important reason for going to school; only a quarter of secondary school students cite academics as the most important reason (Hart Research Associates, 1999).

The popular media have reported on the stress many high school students feel because of the competing demands placed on their time—demands that both detract from and enrich their academic endeavors (see for example, Hart Research Associates, 1999; Schneider, 1999; Springer and Peyser, 1998; Noonan, Seider, and Peraino, 2001; Hong, 2001; Gratz, 2000). For example, in the United States approximately 60 percent of high school sophomores and 75 percent of seniors are employed (Bachman and Schulenberg, 1993; Steinberg and Dornbusch, 1991). It is now commonplace for students, particularly those bound for college, to work 15–20 hours per week during the academic year to earn spending money. In addition, as compared with their counterparts in other countries, U.S. teenagers spend a disproportionate amount of their free time each week in activities that not only fail to support learning, but may actually undermine it. On average, U.S. teens spend 20–25 hours socializing, 5 hours participating in extracurricular activities, and 15 hours watching television during each week of the school year (NCHSSY, 2001a).

Students in advanced study programs are more frequently caught between competing demands on their time as compared with other U.S. high school students. They are involved in field trips that take them out of their academic classes. They are also tapped regularly for academic competitions, honor society committees, student government planning and activities, and fundraising for clubs, all of which remove them from the classroom or impinge on needed study time after school. These students often also play in school orchestras or march in school bands, and they frequently assume leadership positions with school clubs or serve as editors for school publica-

tions.²³ Many of these students consistently carry the maximum number of academic subjects allowed by their schools' schedules, often starting on their homework as late as 10:00 pm. Added to all of this activity is a rushed school schedule that includes a 25–30 minute lunch period in a crowded cafeteria as the only break in the day. Problems at home and with friends and concerns about school safety and personal well-being distract many secondary school students from their academic pursuits. Fully 25 percent of secondary school students report that it is difficult for them to concentrate in class because they are worried about problems at home. This finding is most prevalent among low-income students: 55 percent of these students versus 17 percent of students whose families have few economic worries report that they think so much about home that they cannot concentrate in school (Hart Research Associates, 1999).

Moreover, 40 percent of students say that students who interrupt classes with bad behavior are a major problem that interferes with learning. Indeed, many parents and students view advanced study courses as temporary havens from such disruptions. Almost a quarter of the students surveyed said that teachers not knowing or caring about them as individuals is a big problem as well.

DISPARITIES IN OPPORTUNITIES TO PURSUE AND SUCCEED IN ADVANCED STUDY

Students' educational opportunities and achievement are strongly tied to the beliefs and values of those who educate them (Rosenthal, 1987; Rosenthal, Baratz, and Hall, 1974; Rosenthal and Rubin, 1978; Rutter, McNaughan, Mortimore, and Ouston, 1979). Offering advanced courses in most if not all academic subjects is one way to give students the message that teachers and administrators view participation in higher education as expected and attainable, and that they value the efforts and persistence required to prepare for college.

Most students perform poorly when their teachers do not believe in their abilities, in large part because such beliefs translate into fewer learning opportunities (Lee, 2001; Lee and Smith, 1996; Raudenbush, 1984; Rosenthal and Jacobson, 1968). Many teachers set different learning objectives for students according to perceptions of their abilities. For example, mathematics and science classes taught by teachers who report that their students are of "high" ability focus on developing reasoning and inquiry skills, whereas

²³While these activities are voluntary, and many more students than those in advanced study participate, advanced study students are disproportionately represented among participants. Some attribute this situation to the public's perception of college admission practices.

classes in which teachers report that their students are of “low” ability emphasize instead the importance of mathematics and science in daily life (Gamoran, Nystrand, Berends, and LePore, 1995; Oakes, 1990; Raudenbush, Rowan, and Cheong, 1993; Weiss, 1994). All too often, students who are seen as being of low ability are disproportionately poor or of color (Ingersoll, 1999; Oakes, 1990). Differentiation of coursework and content by the perceived ability of students is characteristic of both formal and informal tracking in most U.S. secondary schools.

Disparities in Participation

High school students can take an advanced class in science and mathematics only if (1) their school offers such classes, (2) the school provides them access to the courses, and (3) they are prepared for such courses. A recent study in California revealed that AP offerings in that state’s 1,100 high schools vary greatly (Oakes et al., 2000): 13 percent offer multiple sections of more than 15 different AP courses; 30 percent provide only single sections of 2 or 3 different AP courses; and 16 percent offer no AP classes at all (Carnevule, 1999; Hebel, 1999). Although these differences in AP offerings are associated with several factors, such as school size and location, there also is a clear correspondence between the availability and breadth of a high school’s AP course offerings and its racial composition. Regardless of the size of the school, the availability of AP courses decreases as the percentage of African Americans, Hispanics, or students of low socioeconomic status in the school population increases, as compared with comprehensive public high schools that serve predominantly white and middle-class students (see Table 2-4). This differential access to AP classes is most stark and most consequential in mathematics and science. The problem also is compounded by the fact that even when schools do offer high-quality advanced mathematics and science courses, students of color and those of low socioeconomic status are much less likely to enroll in them (Atanda, 1999; Horn et al., 2000; Ma and Willms, 1999; Oakes, 1990).

As noted earlier, parental involvement can play a strong role in students’ course selections. Students are more likely to take higher-level mathematics and science courses if their parents are highly educated and knowledgeable about the college admission process and help guide their children’s course selection (Ekstrom, Goertz, and Rock, 1988; Horn et al., 2000; Lee and Ekstrom, 1987; Useem, 1992). When asked to explain the disproportionate enrollment of whites and Asians in advanced classes as compared with other racial or ethnic groups, however, educators attributed this disparity to students’ ability or wise choice of courses without considering the influence of parents on these decisions (Oakes and Guiton, 1995). Some faculty members dismissed

TABLE 2-4 School Racial/Ethnic Disparities in Mathematics and Science Offerings in California, 1998–1999

Proportion African American and Hispanic	Number of AP Math/Science Offerings
Greater than 70 percent	3.8
Less than 30 percent	5.3

SOURCE: Adapted from Oakes et al. (2000).

the disproportionate representation of Hispanics in lower-level courses, even those whose test scores were comparable to the scores of higher-placed white and Asian students, attributing the disparities to differences in students' motivation and choices or to cultural differences in educational values or family support. And studies of schools under court-ordered desegregation have found them to have course placement practices that result in consistently skewed enrollments in favor of white or Asian students over and above what can be explained by measured achievement (Welner, 2001).

Disparities in Outcomes

Even when minority students participate in high-level courses such as AP, end-of-course test results reveal significant differences in outcomes for students from different racial and ethnic groups (see Table 2-5). The disparity in scores on AP assessments between African American, Hispanic, and Native American students on the one hand and white and Asian students on the other are large (as they are for most standardized tests). Additionally, the proportion of minority students who earn scores of 4 and 5 on AP assessments is small (AP examinations are scored on a scale of 1–5, with 5 being the highest score).

It is unclear whether these disparities result from assessments that are biased or reflect others factors, such as the multiple inequities that affect minorities long before they are able to take AP courses or assessments. In any case, education policymakers, school officials, and college leaders must evaluate and implement educational reforms that will improve the academic achievement of economically and educationally disadvantaged students. As a means of improving outcomes, the College Board and many school districts are focusing on improving teaching and learning in the courses that lead to advanced study. As described earlier, this means school districts must redesign the organization and structure of their schools and the allocation of resources to meet the educational needs of *all* students.

TABLE 2-5 Mean Scores^a and Standard Deviations^b on Selected Advanced Placement Examinations, Categorized by Subject and Racial/Ethnic Group

Subject	American Indian/Alaskan	Black/African-American	Chicano, Puerto Rican, and Other Hispanic ^c	Asian/Asian American	White	Other and Not Stated ^d	National Average
AP biology	2.68 [1.23]	2.12 [1.17]	2.32 [1.29]	3.28 [1.31]	3.15 [1.26]	3.18 [1.32]	3.08 [1.30]
AP chemistry	2.17 [1.21]	2.00 [1.14]	2.08 [1.24]	3.07 [1.36]	2.86 [1.33]	2.94 [1.36]	2.84 [1.35]
AP Physics B	2.44* [1.23]	1.77 [1.05]	1.98 [1.20]	2.75** [1.32]	2.82 [1.28]	2.77** [1.31]	2.73 [1.30]
AP Physics C: Mechanics	3.05** [1.54]	2.33 [1.32]	2.62 [1.41]	3.26** [1.38]	3.32 [1.34]	3.21** [1.37]	3.25 [1.37]
AP Physics C: E&M	3.11** [1.63]	2.52 [1.26]	2.74 [1.39]	3.30** [1.43]	3.35 [1.39]	3.13* [1.37]	3.29 [1.40]
AP Calculus AB	2.54 [1.33]	2.12 [1.23]	2.41 [1.33]	3.09 [1.34]	3.11 [1.30]	3.09 [1.33]	3.03 [1.33]
AP Calculus BC	3.20* [1.55]	2.77 [1.42]	3.10 [1.48]	3.66 [1.38]	3.63 [1.36]	3.65** [1.38]	3.60 [1.38]

SOURCE: Adapted from College Entrance Examination Board (2000c).

^aThe differences between any given group mean and the national mean are significant at .01 except where indicated: *difference between group mean and national mean is significant at .05; **difference between group mean and national mean is not significant.

^bGiven in brackets.

^cThis column shows the weighted mean and standard deviation as calculated from three groups reported by the College Board—Chicano/Mexican American, Puerto Rican, and Other Hispanic.

^dThis column shows the weighted mean and standard deviation as calculated from two groups reported by the College Board—Not Stated and Other and Not Stated.

Some of the most effective strategies for improving student success in advanced study go far beyond merely adding more advanced study classes in high schools with underserved student populations (although access to these classes is important). Strategies that have proven effective include reducing class size (Grissmer, 1999); eliminating low-level academic courses that do not prepare students academically (Frome, 2001; NASSP, 1996); enhancing professional development to help teachers incorporate research-based instructional, curricular, and assessment strategies in their classrooms (see Chapter 7, this volume); hiring and retaining qualified teachers to teach in rural and inner-city schools; providing information to parents about the long-term benefits of students' participation in rigorous academic programs

(Dornbusch, 1994; Eccles and Harold, 1996);²⁴ implementing and supporting supplementary educational opportunities; and increasing student access to skilled counselors and mentors who can help them plan and implement strategies for educational attainment and achievement.

CONNECTIONS BETWEEN ADVANCED STUDY AND HIGHER EDUCATION

High School–College Interface Coordination and Articulation

Most people agree that an important goal of high school is to prepare students for further education and future work. However, a high school diploma currently does not guarantee success in either domain. This situation derives partly from a decentralized and disconnected system of K–12 education in which students encounter differing sets of requirements and expectations as they move from elementary school to the middle grades and on to high school. The disjuncture is exacerbated further by the lack of articulation and coordination between secondary and higher education in terms of what students need to succeed academically in college (Kirst, 1998).

In 1999 almost 66 percent of high school graduates nationwide had completed some college by the time they reached age 28. This number represents an enormous increase as compared with the proportion of 28-year-olds who had completed some college in 1971 (43 percent). Yet despite this increase in matriculation, the proportion of high school graduates who have completed a baccalaureate degree by the time they reach age 28 has risen by only 10 percentage points (NCES, 2000a).

Many policymakers and higher education faculty view students' inadequate preparation for the rigorous demands of college as a failure on the part of high schools. Others contend that the situation represents not a failure on the part of high schools, but a misunderstanding of what it means to be prepared. The diverse nature of colleges and the corresponding diversity of their academic offerings and expectations contribute markedly to this lack of understanding. Given this diversity, teachers and guidance counselors can be unclear about what students should know and be able to do before they begin college work.

A cursory review of the placement examinations administered to incoming freshmen at many institutions is all that is required to reveal just how varied these expectations are. Even in the same state, each public institution

²⁴See also The National Coalition for Parent Involvement in Education at http://www.ncpie.org/Resources/Subject_HigherEducation.html (February 11, 2002).

of higher education often has a different set of expectations for placement of students in its system, making it doubly difficult for high schools to know just what preparing their students for college means (Kirst, 1998). This lack of understanding may leave some students with limited college options many years before they are ready to make such a choice.

What is clear, however, is a pervasive and enduring belief that AP or IB courses offer an advantage to students in the college admission process. This belief has led to ever-increasing numbers of students enrolling in multiple AP courses or seeking IB Diplomas (see Chapters 3 and 4, this volume). The popular media, college guidebooks, and even the colleges themselves promote the potential positive edge in admission gained from participation in these programs.

Advanced Study as a Link Between High School and College

Advanced study programs such as AP span the boundaries of secondary and higher education. The content and structure of advanced study programs and the learning experiences they offer to high school students can provide one of the foundations for academic success in higher education. Students and their parents look to these programs to facilitate students' admission to college, to help them succeed in college-level work once admitted, and to yield college credit and the possibility of proceeding directly to more advanced courses when the students matriculate in college. High school teachers expect these programs to provide motivated and well-prepared students with opportunities to gain the prerequisite content knowledge and habits of mind that will make them successful in college.

In turn, colleges and universities want to enroll highly qualified students who have the background and motivation to succeed in college courses. They want students who are well prepared and well educated. Colleges and universities look to and rely on advanced study to prepare students for the rigors of higher education. High school advanced study courses in science and mathematics are particularly important in establishing a foundation on which to build further study in these disciplines. Students, parents, high school guidance counselors, and even some college faculty may view these introductory courses in science and mathematics as "gatekeepers." Science and mathematics are among the most hierarchical subjects in higher education and typically require sequential courses of study extending over many years. If the advanced study programs that serve as introductions to these disciplines are not well constructed, subsequent learning is likely to be adversely affected.

The availability of both government and private funds has begun to catalyze fundamental changes in the ways science and mathematics are taught at the undergraduate level, especially in introductory courses (see, for example, NRC, 1999d; Rothman and Narum, 1999). Cutting-edge concepts and skills from the disciplines are being integrated into introductory classes and laboratories. Information technologies increasingly are being woven into the fabric of teaching and learning for large numbers of undergraduates. However, this teaching and learning revolution has yet to reach many campuses, and advanced high school courses in the sciences continue to be modeled on traditional approaches. This tendency is reinforced in AP science courses by the College Board's practice of basing its course outlines on surveys of institutions that accept large numbers of AP students. This practice can reinforce the status quo for AP courses instead of encouraging change to reflect emerging best practices in the disciplines involved.²⁵

The Role of Advanced Study in College Admission Decisions

How Admission Decisions Are Made. Although much is known about how colleges make admission decisions, there is clearly a limit to what can be known about actual practices across institutions. The committee recognizes that many different individuals ultimately make these decisions, and that the decisions they make are based on particular circumstances and available information of varying quality. Thus, the discussion below can explore only in part the full range of processes and practices involved.

The primary role of admission officers at all colleges and universities is to assemble a class from among the qualified applicants. In some states, legislative mandates determine who must be admitted to public colleges and universities. For example, the Top 10 Percent Law (officially House Bill 588) guarantees that Texas high school graduates who rank in the top 10 percent of their senior class will be admitted to any state institution of higher learning. At other postsecondary institutions, both public and private, admission decisions are made primarily on the basis of numerical formulas that include a student's high school grade-point average (GPA), class rank, completion of specified numbers of courses, and performance on the ACT (American College Testing Program) or SAT I and sometimes one or more SAT II subject tests. Some of these institutions also consider information on applicants'

²⁵An exception to this trend is in AP calculus, which is based on emerging research about teaching and learning in that subject. This difference between calculus and the science subjects that were investigated by the committee is considered in greater detail in Chapter 10 and in the panel reports prepared for this study (a summary of these reports is provided in Appendix A; the full reports can be found at <http://www.nap.edu/catalog/10129.html>).

experiences, extracurricular activities, talents, and backgrounds. Students who meet established standards are typically admitted as long as space is available. This approach to admissions allows institutions to identify qualified applicants efficiently from a very large pool. With this approach, AP and IB play a role only when grades earned in those classes are given extra weight in computing GPAs or establishing class rank. Students who do not have access to AP or IB courses are at a disadvantage in this type of admission process unless provisions are in place to give equal weight to other kinds of advanced courses available to them. Thus, colleges and universities that use a formula to make admission decisions often give special consideration to grades earned in honors or college preparatory courses as well as to AP and IB grades.

In contrast with both of the systems described above, some institutions, particularly those interested in shaping their incoming classes in accordance with institutional goals and priorities, use a very different approach. Admission officers at these colleges individually read applications (sometimes more than once), consider information about students that is more subjective in nature, and examine how each student might contribute to the values and goals of the institution. Evaluations of students in these situations usually take into account both what an individual applicant has accomplished and the context of the high school from which he or she will graduate. For example, students who take no honors or AP classes at schools that offer such programs are viewed differently from those who take no such classes at schools where they are unavailable. Similarly, those who attend schools where participation in extracurricular activities is limited by school policy are not evaluated with the same expectations for participation as those who attend high schools that encourage participation in a wide variety of activities. School profiles,²⁶ reports of admission officers who visit many high schools, and the academic reputations of particular schools are used to pro-

²⁶A profile is a concise overview of the high school and its offerings. Profiles vary in quality, but a good one will indicate the highest-level courses offered in each academic area, describe the levels available (for example, honors, gifted and talented, college preparatory, remedial) for each grade, and make clear the degree of challenge. This profile allows an admission reader to compare the applicant's transcript against the offerings of the school. In addition to course-level information, a profile also includes demographic information about both the school and the community; economic information, including percentage of school population on free or reduced lunch; the diversity of the student body; the percentage of graduates attending 4-year colleges; educational options in the community (mentorships or access to college courses taught on local college campuses, for example); college acceptance lists (where previous graduates were accepted or matriculated); SAT/ACT ranges; GPA distribution; and AP or IB score distributions by subject that serve as important indicators of how well the high school classes are aligned with the AP or IB program syllabi.

vide admission officers with needed information about the high schools attended by applicants.

The Roles of AP and IB in the Admission Process. To better understand the role played by AP and IB courses and examination results in college admission decisions, the committee conducted an informal survey of deans of admission from 264 U.S. colleges and universities.²⁷ Approximately half responded. The survey was designed to shed light on three broad issues related to the college admission process: (1) how AP and IB courses on an applicant's transcript are used in admission decisions, (2) the extent to which applicants' chances for admission are affected if they do not take IB or AP courses because the courses are not offered at their high schools, and (3) the role played in admission decisions by AP and IB examination grades or by a lack of reported results.

The survey revealed that, regardless of their specific goals, the most important priority for admission officers at selective schools is to admit students who can take advantage of the academic strengths of the institution as well as contribute to the education of their peers. Because past performance is deemed a strong predictor of future performance, admission officers carefully review applicants' transcripts to determine how well and to what extent the applicants have taken advantage of the school- and community-based opportunities available to them in high school.²⁸ Admission personnel generally view the presence of AP or IB courses on a transcript as an indicator of the applicant's willingness to confront academic challenges.²⁹

The presence of AP and IB courses on a student's transcript (if such courses are available at the applicant's high school) is of greatest importance for admission to highly selective schools seeking students who have taken

²⁷Using the 1994 Carnegie classifications for ranking undergraduate institutions, schools were placed into four broad categories: national universities, national liberal arts colleges, regional universities, and regional liberal arts colleges. Institutions from these four categories were then sorted by their selectivity in the admission process, as defined by the percentage of applicants admitted. Surveys were sent to the 50 most selective national liberal arts colleges and the 50 most selective national universities, as well as every seventh school on the remaining lists (a total of 264 institutions). Reminders were sent to deans who had not returned their survey forms by the deadline. This process resulted in a return of surveys from 133 institutions. Admission selectivity among the sample of surveys that were completed ranged in percentage of applicants accepted from a low of 11 percent to a high of 100 percent.

²⁸Admission officers use two primary sources of information for determining what was available to students at different high schools: first-hand information gathered by admission staff during recruiting trips, and the high school profile, discussed above.

²⁹AP and IB courses may also serve as indicators of the quality of the academic program offered by the applicant's high school and hence assist in comparing students from different schools.

maximum advantage of the academic opportunities available to them. AP and IB courses are somewhat less important factors for admission at colleges where a larger percentage of applicants are admitted. Nonetheless, many of these colleges use the presence of AP and IB courses as an indicator of the strength of the applicant's academic preparation. AP and IB play little to no role in admission decisions at colleges where the vast majority of applicants are accepted.

There are generally two types of high schools that do not offer AP or IB courses. First are both public and private schools that, for institutional reasons, elect not to offer AP and IB and instead provide their own rigorous curricula. Many of these high schools have national reputations for excellence, and admission officers know the levels of challenge the students in these schools experience. Second are schools typically located in areas where sufficient resources or qualified personnel are not available to mount such a program or where the demand for such courses is deemed to be low. The committee was concerned primarily with the outcome for students from this second group.

When asked what the effect on admission decisions is if AP or IB classes are not available at an applicant's high school, deans from virtually every college or university replied that a lack of AP or IB courses at an applicant's high school would not have an adverse effect on a student's gaining admission to their institution if the student had taken the most challenging courses that were available and done well in them. Some admission officers indicated that they might look for evidence that students lacking access to rigorous opportunities in school tried instead to participate in similar kinds of academic opportunities outside of school. A very small number of deans indicated that there might be indirect consequences for students from schools with limited advanced course offerings. For example, a small number of deans reported that they are more likely to "dip deeper" into a class (i.e., accept students with a lower class rank) in high schools with solid academic programs than in schools with less solid programs. Thus, the number of AP and IB courses is sometimes used as an indicator of a school's academic commitment. Of course, while offices of admission consciously avoid penalizing students who do not have access to advanced study courses or programs in their high schools, the lack of access to such courses also could result in students' from these schools being less prepared and less successful if they are admitted to selective institutions.

The survey also addressed the issue of students who have access to AP and IB courses at their high schools but choose not to enroll in them. Deans from the most selective schools responded consistently that this decision would likely place an applicant at a disadvantage. When evaluating a student's program against a high school's course offerings, the most selective schools effectively require, in the absence of some compelling reason, that success-

ful applicants take the most demanding curriculum available to them. For some students, this may mean they are expected to take four to six AP courses during their high school years or three higher-level IB courses during their senior year. It also implies that students who attend schools where AP and IB courses are offered as junior year options are expected to have taken such courses in their junior year as well.

AP and IB Examination Grades and the Admission Process

AP and IB examinations are administered each May, and scores are not usually available until July. Therefore, final examination grades for AP and IB courses taken during the senior year of high school are not a factor in admission decisions, although they are a factor in credit and placement decisions. Many educators contend that this makes it easy for seniors to reduce their level of commitment to academics once admission letters have been mailed, sometimes as early as December of the senior year for those students who have applied for early decision or rolling admission.

If an applicant has taken AP or IB classes in tenth or eleventh grade but has not submitted scores, deans at most of the more selective colleges and universities included in the committee's survey indicated that they interpret the student's decision cautiously. Many observed that AP examinations are expensive and that applicants may not have taken them for financial reasons. Others noted that teaching is uneven from school to school and that it would be unfair to make assumptions about an applicant on the basis of information not provided. If, however, a student fails to submit scores, he or she has, in the words of one respondent, "missed a chance to strengthen the application." A few of the most selective schools actively search for AP or IB scores on an applicant's transcript; deans from these schools mentioned that the lack of an examination score would be addressed in a student interview if the opportunity arose.

Given the increase in the number of examinations being administered to sophomores and juniors, it is anticipated that examination scores may play a greater role in the admission process in the future. Deans from colleges and universities familiar with the IB program noted to the committee that the practice of some high schools of providing predicted scores³⁰ was helpful in the evaluation of an applicant.

³⁰IB teachers are required to submit "predicted grades" for each student before the year's end. Predicted grades are used for a variety of purposes, including teacher evaluation and determination of grade distributions. The decision whether to release predicted grades to students, and presumably to colleges, is left to the individual high schools (IBO, 2000d). See additional details in Chapter 4, this volume.

College Credit and Placement Based on Advanced Study

The College Board and the IBO do not award credit or mandate specific placements, although both provide some guidance about appropriate practice. Thus individual colleges and universities (or departments within them) decide whether to award credit for AP and IB examination scores they regard as sufficiently high.

More than 2,900 colleges and universities accept AP test scores, and approximately 750 postsecondary institutions recognize IB scores. IB students traditionally have more difficulty than their AP counterparts obtaining college credit or placement for their scores. This situation is changing somewhat as colleges become more familiar with IB course content and requirements and gain more experience with IB students. However, because of the lingering reluctance of some schools to grant credit or placement for IB, some IB students also take AP assessments. This is a challenging undertaking for IB students because both sets of examinations are administered in May, and the dates may overlap.

Reducing Time to Degree

One of the factors contributing to the rapid increase in AP and IB enrollments is the perceived potential benefit of earning inexpensive college credits that can reduce time to degree and consequently decrease overall tuition costs.³¹ The extent to which students actually take advantage of this opportunity for acceleration in college and the resulting savings in tuition, is not well documented, however. Some students spend the same amount of time as other undergraduates, using these credits instead to reduce overall course loads, to pursue coursework that their schedules would not otherwise allow, or to take additional courses in a subject area.

Using AP and IB for Placement or Exemption from Required Courses

As noted above, in addition to being able to graduate early, students can use their AP and IB credits to reduce overall course loads or to meet college prerequisite or distribution requirements, freeing time in their schedules to

³¹Approximately 1,400 institutions offer sophomore standing to students with sufficient AP credit (College Board, http://www.collegeboard.org/ap/students/benefits/soph_standing.html [November 27, 2001]). Increasing numbers of colleges (for example, state universities in California, Florida, and Washington) are awarding credit and sophomore standing to IB students with IB diplomas.

take courses they find more interesting or challenging.³² Indeed, for many high-achieving students, the opportunity to place out of introductory courses and move directly into upper-level classes is a greater motivator than early graduation. Some colleges explicitly support this use of AP and IB scores by offering upper-level course placement to students who earn qualifying scores even if the institution does not award credit. Many high school counselors and teachers encourage their students to use their AP and IB credits in this manner when they enter college, especially when the introductory courses they would otherwise be required to take are large lecture classes or are perceived not to be sufficiently challenging.

At the same time, using credits from these examinations to fulfill distribution requirements means that students can potentially graduate from college without ever having taken courses in certain subject areas. For example, a student with AP biology credits may never have to take another course in science. Some institutions have attempted to minimize this practice, requiring that students address the school's distribution requirements by enrolling in courses that are at higher levels than those taken in high school.

In contrast, some students decide not to use their AP or IB credits to place out of introductory courses because they believe they will benefit from taking the subjects again in college. The biology, physics, and chemistry panels that provided information for this study agreed that most students would benefit from retaking these courses in college. The mathematics panel did not agree, suggesting that there is typically little benefit for qualified AP or IB students in retaking introductory calculus in college unless their institutions require them to do so.

Students also may forego upper-level placement because they want to avoid the risk of doing poorly in upper-level courses during their first year in college or because they believe retaking a course in college would result in their receiving a higher grade than if they enrolled in a more advanced course. Deans from a very small number of institutions participating in the committee's survey indicated that they offer transitional courses to students who place out of introductory-level courses but do not advance to the next course because of either the student's own decision or that of the institution.

It may also be noted that students who take AP and IB courses and then repeat those same courses in college present a particular challenge to college faculty. It can be difficult to teach these students in the same class with those who may have only a basic understanding of the subject.

³²Some colleges do not allow students to use AP or IB credits to fulfill distribution or major requirements; others grant AP or IB credit for first-year courses only after students have successfully completed a second-level course in the same subject.

Institutional Decisions

In general, colleges and universities make decisions about granting AP and IB credit and placement in the same way they decide about accepting credits from other colleges. That is, university or department officials consider the content of the course, its perceived difficulty, associated laboratory activities (in the case of science courses), and the student's level of achievement. They compare the course with similar offerings at their own institutions. Placement (rather than credit) decisions also may take into account the capabilities of the particular student and may be aided by the use of a department's own placement test. This process is consistent with recommendations made by the College Board to its member institutions. In some publicly funded institutions,³³ the granting of credit for a given AP or IB score may be legislatively mandated or set by institutional policy.

The IBO does not provide guidelines for colleges to use in making decisions about credit or placement. IB is an international program, and consequently IB students attend colleges in many countries, each with its own standards and examination policies. However, the IBO offers to assist administrators and department heads at U.S. colleges or universities who are unfamiliar with the IB program in making appropriate decisions with regard to the acceptance of IB examination scores for credit or placement.

In science, decision making at the department level may involve interviewing the student and reviewing his or her high school course syllabus and laboratory notebooks. In other departments, examination scores alone may suffice. In mathematics, most departments accept an AP examination score in calculus without question. This practice is the result of faculty experience with what AP students know and are able to do, and the similarity between AP and college calculus courses.

Denial of Credit or Placement

Although the College Board encourages colleges to award academic credit for an AP score of 3 or higher, and the American Council for Education endorses this stance (College Entrance Examination Board, 2000a), nearly half of the colleges in the United States that accept AP credits do not abide by the College Board's standards (Lichten, 2000). Lichten found that while most 4-year colleges accept 4's and 5's for credit, only 55 percent accept 3's. Overall, only 49 percent of AP test takers receive college credit, even though

³³This point applies only to publicly funded institutions.

two-thirds of them are qualified for college credit according to the College Board.³⁴

There are various reasons for the reluctance of some colleges to award college credit as generously as entering students have come to expect and as frequently as the College Board recommends. For example, university faculty and administrators may not believe that students taking AP courses have undertaken work that is equivalent to the courses at their institution or that students have engaged the concepts of the discipline as deeply as they would in college.

Variability of Credit and Placement Decisions

Survey of Mathematics and Biology Departments. To gain a better understanding of the ways in which postsecondary institutions make credit and placement decisions about AP and IB, the committee sent an informal questionnaire about these issues to the departments of biology and mathematics at 131 colleges and universities.³⁵ The respondents represented national universities and liberal arts colleges, as well as regional colleges and universities located in the Midwest, North, South, and West. The institutions that responded included research universities, colleges, highly selective institutions, and institutions with open-admission policies.

It is important to note that a precise interpretation of the survey data was difficult. Response rates were less than ideal. The survey questions unfortunately did not probe sufficiently for detail or allow respondents to qualify their answers. Nevertheless, the data do provide useful information about how placement decisions are actually made.

The majority of the biology departments that responded to the survey offer two different introductory biology courses—one designed for potential majors and the other for everyone else. Other survey findings include the following:

³⁴The College Board is currently studying the validity of a grade of 3 on AP examinations.

³⁵Departments of biology and mathematics to which survey forms were sent were selected from a list of schools gathered from the Gourman Report: *A Rating of Undergraduate Programs in American Universities* (Gourman, 1999). Also selected were departments in every third school from the alphabetical list of the Oberlin Conference schools and every seventh school from the Carnegie Foundation's listings of institutions of higher education by institutional type (Bachelors I and II, Masters I and II, and Doctoral I and II institutions—available at <http://www.carnegiefoundation.org>). This process resulted in the selection of 131 schools. The chairs of the biology and mathematics departments from these institutions were sent the questionnaire by electronic mail. Responses were received from 43 chairs (33 percent) from departments of biology and 59 chairs (45 percent) from departments of mathematics.

- The vast majority of these departments award college credit for AP, and sometimes for IB.³⁶
- The amount of credit awarded almost always depends on the score earned. For example, a student with an AP score of 5 or an IB score of 7 might earn up to eight credits (the equivalent of two semester courses with laboratory), while a student with a score of 3 or 4 might earn only four credits.
- Some departments are willing to accept an AP score of 3 or an IB score of 5, but the majority look for 4's or 5's on AP tests and 6's or 7's on IB tests. Two institutions grant credit or placement only for an AP 5 or an IB 7.
- Credit and placement policies at most institutions do not vary significantly between majors and nonmajors.
- A small proportion of the schools reported using indicators other than the test scores in making placement or credit decisions. In order of descending frequency, these additional factors are student interviews, placement tests, the high school's reputation, and the student's laboratory manual.
- Only two of the schools that responded have developed a special course as a transition to higher-level science for students with AP or IB credits.

Approximately half of the mathematics department chairs that responded to the survey indicated that their departments offer only one sequence of calculus. The others offer different sequences—one for mathematics, engineering, and physical science majors and the other for life science and other majors. A variation on this last organizational structure is a third sequence for business majors. Additional survey findings are as follows:

- A large majority of the mathematics departments offer *credit* to students with qualifying AP scores without considering any additional factors. However, almost a third require a departmental test and/or an interview with the student before determining *placement* in courses beyond the introductory level.
- Mathematics departments routinely offer credit for scores of 4 and 5 on AP Calculus AB or BC examinations. Among the schools that accept IB, most consider a score of 5 or higher on the Higher Level examination to be acceptable.³⁷

³⁶Many of the biology departments were unfamiliar with the IB program and had never been asked to consider an IB score for credit or placement. These institutions restricted their responses to AP.

³⁷Many respondents did not know of a policy for accepting IB credits, and some of the departments reported that they do not award IB credit.

- Very few departments indicated that they would accept any scores from the IB Standard Level course in Mathematics Methods.
- Special sections of mathematics (both higher-level calculus and other areas of mathematics) are sometimes offered to students who score 4 or higher on an AP calculus examination. This practice is most common among schools that emphasize mathematics and engineering.

EPILOGUE

From the perspective of higher education, advanced study in mathematics and science has both advantages and disadvantages. In theory, both the AP and IB programs should lead to learning of science and mathematics content at a more advanced and deeper level than would occur if students had taken only introductory high school courses in these subjects. Furthermore, by creating de facto standards for the kinds of knowledge and skills students are expected to learn in a subject area, these programs allow colleges and universities to gauge more easily the academic experiences that applicants and entering students have had during their high school years as compared with students who did not enroll in these courses or programs.

As detailed in Chapters 3 and 4, however, the academic experiences of the students in these programs can be highly variable. Additionally, some college-bound students may not have access to such opportunities even where they do exist. Therefore, it remains a challenge to provide appropriate college courses for this broad array of first-year students. This is a concern in particular for smaller institutions that cannot offer a large number of options for incoming students in each discipline.

The Advanced Placement Program

The Advanced Placement (AP) and International Baccalaureate (IB) programs are the two most widely known and nationally recognized models for advanced study. Students in AP and IB courses are provided opportunities for both acceleration and advanced study in high school mathematics and science. Both AP and IB are examination-based programs, designed for well-prepared and highly motivated students in their last 2 years of high school. Both certify a student's level of knowledge with a score on an end-of-course assessment that is recognized and valued nationally and internationally. And both programs are being challenged by a rapid expansion in the number of participating schools and students and by uses of test scores that probably were unforeseen when the programs were first established nearly 50 years ago.

Despite their ostensible similarities, the two programs are actually quite different with respect to their goals, their organization, and the ways in which they assess student learning. This chapter presents a detailed review of the AP program; a similar review of the IB program is provided in Chapter 4, this volume. The first section gives an overview of the AP program; the sections that follow address in turn AP curriculum, instruction, assessment, and professional development.

OVERVIEW

The AP program is the predominant national model for advanced courses in high school. It was established in 1955 to challenge able and well-prepared secondary students with college-level work. Supported by the Educational Testing Service (ETS), the College Board develops AP course descriptions and yearly end-of-course examinations that represent an attempt to mirror the coverage typical of college-level introductory courses. On the basis of demonstrated achievement on the examinations, students may be

awarded college credit or advanced placement in higher-level college courses (see Chapter 2, this volume). A high school can elect to offer one or more AP courses simply by scheduling the courses and assigning a teacher. Individual students can elect to take any number of AP courses, as their high school allows, and there is no requirement from the College Board that students who take AP courses and receive the AP designation on their high school transcript take the examination.¹

The College Board has developed an AP Diploma that is being offered in the academic year 2000–2001 in 20 school districts across the United States. To earn the diploma, students must complete five AP courses and receive a qualifying score (3) on each of the five examinations. The five courses must include at least one in each of the core areas of mathematics, science, language arts, and history, along with one AP elective course. The College Board plans to offer the AP Diploma in all schools in the 2001–2002 school year.

During the past 45 years, the AP program has grown from a small program that served only the top students from largely suburban public and private high schools to one that now is available in a much more diverse group of approximately 62 percent of the nation's high schools. The program experienced a decade of rapid growth during the 1990s as the number of students taking AP examinations increased from 206,000 to more than 760,000 a year. The number of examinations administered in a year rose from 277,000 in May 1990 to 1,277,000 in May 2000 (College Entrance Examination Board [CEEB], 2000c).

In its report *Access to Excellence*, the Commission on the Future of the Advanced Placement Program (CFAPP) (CFAPP, 2001) describes significant challenges to the program that have accompanied this rapid growth. Since approximately 34 percent of students enrolled in AP courses do not take the AP examinations, the first challenge noted is how the program can maintain the quality of courses and examinations and the validity of the AP credential. Second, students from urban, rural, and poor districts are underrepresented among those who take the AP examinations, and minority students are less likely than other students to take AP courses when they are offered and to achieve success on the examinations. Therefore, the commission notes the critical importance of finding ways to increase the equity of access to AP courses. The report sets forth goals and recommendations that would broaden the aim of the program by positioning it to enable many more students to experience college-level courses and earn college credit while in high school.

¹Some states and school districts require that students who receive an AP credit on their transcript take the corresponding AP examination. This requirement is most common in districts where students receive financial support for taking the examinations.

At the same time, the commission emphasizes that the AP program needs to adhere to the following set of expectations to maintain program quality and oversight:

- While continuing to reflect college-level expectations and cooperation between schools and colleges, AP courses and examinations also should reflect changes in the disciplines and in pedagogy and provide models of effective instruction.
- The reliability of the AP examinations in measuring student achievement at the introductory college level must be ensured.
- Standards for AP programs in schools and school systems, for AP teachers, and for teachers' professional development should be formulated and implemented.
- The program should focus on expanding access for underserved schools and populations by strengthening the preparation of students in courses that precede AP courses.

AP CURRICULUM

Consistent with the purpose of the program, AP courses are designed to be equivalent to general introductory college courses with respect to the range and depth of topics covered, the kinds of textbooks used, the kinds of laboratory work done by students, and the time and effort required of students (CEEBS, 2001a). A course description for each AP course briefly outlines the topics that may be included on the end-of-course examination, describes the examination format, and provides sample questions. The course description and teacher's guide for each AP subject area are available for a fee to teachers, who can use them as the basis for developing the curriculum for their own courses (course descriptions can now be downloaded from the College Board's Web site for free). Individual teachers are given great leeway in structuring AP courses for their classrooms. Thus, the curriculum for AP courses varies from classroom to classroom in both design and implementation, including which topics are emphasized, how the topics are related, how the content is sequenced, and how much time is spent on laboratory activities.

Development of AP Courses

College faculty members in each discipline, along with experienced AP teachers, are recruited by the College Board to serve on a development committee for each AP course. The traditional strategy for determining the content and skills to be covered in an AP course and on the AP examination

has been to survey the department faculty from colleges and universities receiving the most AP score reports in a discipline. The faculty who serve on the subject-specific development committees synthesize the information from these surveys and construct a course description they believe best represents the consensus view of the college-level introductory course (CFAPP, 2001, p. 22). The development committee for a course develops both the topic outline and, with help from ETS experts, the course examinations. The committee prepares the course description for each subject and compiles a list of the textbooks used most frequently in the corresponding college course. Development committees for AP science courses may also recommend laboratory activities that are representative of work done by college students in the corresponding introductory course. This entire process is repeated every 5 to 6 years.

One result of this process is that until curricular changes have become common in introductory college courses, those changes are not reflected in the AP course descriptions and examinations. Thus, some disciplinary leaders have contended that, with the growth in AP participation and the program's influence on high school curricula, the AP course development process has the potential to slow the implementation of desirable curricular reforms.

In contrast, the development of AP calculus during the 1990s provides a model for implementing rather than impeding curricular change. The AP Calculus Development Committee used a broader, more forward-looking strategy for revising the description and the examination specifications for this course by collaborating with experts in mathematics content, curriculum, and pedagogy. The committee became an active participant in the calculus reform movement at the college level and the National Council for Teachers of Mathematics–driven standards movement at the precollege level.² According to CFAPP, “We believe that such strategies must be replicated whenever AP course descriptions are reviewed and revised. Leaders in the disciplines, pedagogy, and research must all play a role in order to create the highest quality curriculum possible” (CFAPP, 2001, p. 12). This committee concurs with that recommendation.

Content of AP Courses

Each AP course description, or acorn book to use the popular term, includes a topic outline. The major topics on the outline for biology, chemistry, and physics are accompanied by percentages. However, the percent-

²More information about the AP calculus development process is available at *AP Calculus for a New Century* by Dan Kennedy, http://www.collegeboard.org/ap/calculus/new_century/index.html (November 26, 2001).

ages may have different meanings for different subjects. For example, in the course description for AP biology, the percentages for each major topic and subtopic to be covered in a course are indicated (CEEB, 2001a, pp 5–6). In the course description for AP physics, the “percentage goals for the examination” are given (CEEB, 2001d, pp.16–20). In AP chemistry, the percentages indicate “the approximate proportion of questions on the multiple-choice portion of the examination that pertain to that topic” (CEEB, 2001c, pp. 6–8).

A listing of subtopics is provided for each major topic. The portion of the AP chemistry topic outline related to chemical bonding illustrates the level of detail provided by the topic outlines for each subject (CEEB, 2001c, p. 6):

B. Chemical Bonding

1. Binding forces

- a. Types: ionic, covalent, metallic, hydrogen bonding, van der Waals (including London dispersion forces)
- b. Relationships to states, structure, and properties of matter
- c. Polarity of bonds, electronegativities

2. Molecular models

- a. Lewis structures
- b. Valence bond: hybridization of orbitals, resonance, sigma and pi bonds
- c. VSEPR [valence shell electron pair repulsion]

3. Geometry of molecules and ions, structural isomerism of simple organic molecules and coordination complexes; dipole moments of molecules; relation of properties to structure

The topic outline is intended to indicate the scope of the course, but not necessarily the order or depth in which topics are taught. Teachers are told that although the examination is based on the outline, they may wish to add further topics (CEEB, 2001b, p. 12).

Laboratory Requirement for AP Science Courses

Because each AP course is developed independently, information on laboratory work provided to teachers of AP science courses varies among disciplines. There is a common recommendation that at least one double period per week in AP chemistry and AP physics and two double periods per week in AP biology be spent in laboratory work. The AP physics course description does not recommend specific laboratory exercises, but rather presents survey results on laboratory emphases in typical introductory col-

lege physics courses and describes the diversity of approaches used. The May 2002–May 2003 course description for AP chemistry includes *A Guide for the Recommended Laboratory Program for Advanced Placement Chemistry* (CEEB, 2001c, pp. 36–51). The guide recommends 22 laboratory activities,³ with the qualification that it is unlikely that every student will complete all 22 activities while enrolled in an AP chemistry course (CEEB, 2001c, pp. 45–49). Students who have completed a first-year chemistry course will likely have been exposed to many of these activities prior to the AP course. For AP biology teachers, an AP biology student laboratory guide and accompanying teacher’s guide are available. Like the recommended chemistry activities, many of the biology laboratories will likely have been part of a first-year biology program. Biology teachers are encouraged to substitute alternative investigations as appropriate if they will enable students to meet the objectives stated in the guide.

While the importance of including laboratory work in the curriculum is emphasized to teachers, the interrelationships among curriculum, assessment, and instruction are also highlighted. The AP physics course description suggests that laboratory experiences should help students understand the topics being considered in the course and may improve test performance overall (CEEB, 2001d, p. 8). The description for AP chemistry states, “Data show that student scores on the AP Chemistry Exam improve with increased time spent in laboratory. This correlation is expected to be even stronger now that a question concerned with laboratory experiences is included on the examination each year” (CEEB, 2001c, pp. 43–44). Recent guidelines given to the AP science course development committees include a charge to assess knowledge about laboratory skills and experimentation.

Additional Guidance Provided to Teachers About Curriculum Development

The College Board asks AP biology teachers to stress understanding of concepts rather than memorization of terms and technical details. The rationale provided is that students who understand the topics on a conceptual level will do better on the national examination. Teachers are told that the AP biology examination will assign increasingly less weight to specific facts, and that students should be encouraged to focus on understanding important relationships, processes, mechanisms, and potential extensions and applications of concepts. According to the College Board, questions on future

³The recommended activities include some processes and procedures that can often be combined and incorporated into a single laboratory investigation.

examinations can be expected to test students' ability to explain, analyze, and interpret biological processes and phenomena more than their ability to recall specific facts (CEEB, 1999a). With regard to the issue of depth vs. breadth, the AP physics course description states, "concentration on basic principles of physics and their applications through careful and selective treatment of well-chosen areas is more important than superficial and encyclopedic coverage of many detailed topics" (CEEB, 2001d, p. 4).

Although the stated goals for AP courses emphasize the importance of depth of understanding of fundamental concepts, the materials provided to teachers give little specific and detailed advice for designing a coherent curriculum. The AP biology course description goes the furthest in articulating the principal concepts underlying the discipline and in organizing knowledge around them: "Emphasizing concepts over facts makes the content of a biology course less overwhelming and more meaningful. A biology course has more structure and meaning when the key concepts for each topic are placed in the broader context of unifying themes" (CEEB, 2001a, p. 4). To this end, the course description identifies three main subject areas that are crosscut by eight biological themes. The College Board presents a brief, open-ended framework for conceptual knowledge and encourages teachers to continue the articulation and organization of knowledge themselves (see Table 3-1).

TABLE 3-1 Some Applications of the Energy Transfer Theme to the Three Main Subject Areas

Theme	I. Molecules and Cells	II. Heredity and Evolution	III. Organisms and Populations
	Plants transform light energy into chemical energy.	A cell must spend energy to transcribe and translate a gene because entropy decreases as monomers are organized into complex macromolecules.	Energy flows from producers to consumers in an ecosystem.
III. Energy Transfer	A proton gradient across membranes powers the synthesis of ATP in mitochondria, chloroplasts, and prokaryotes.	Energy released by the hydrolysis of ATP is used by cells in DNA synthesis, transcription, and translation.	Ion pumps in membranes reestablish a transmembrane resting potential after a neuron fires an impulse or a muscle fiber contracts.

SOURCE: Adapted from CEEB (2001a, p. 17).

NOTES: ATP = Adenosine Tri-Phosphate. The College Board encourages teachers to continue identifying ways in which the eight major themes can be applied to the three major subject areas.

The teacher's guide for AP biology (Schofield, 2000) encourages teachers to develop a curriculum for conceptual or thematic understanding. The guide illustrates a shift in emphasis of AP biology examination questions away from factual listings of information, as illustrated by the 1989 free-response question about cell energetics, and toward conceptual understanding, as illustrated by the 1995 question. The following examples are taken from that guide (Schofield, 2000, pp. 24–25).

Factual free-response question about cellular energetics from the 1989 AP biology examination:

Explain what occurs during the Krebs (citric acid) cycle and electron transport by describing the following:

- a. The location of the Krebs cycle and electron transport chain in the mitochondria
- b. The cyclic nature of the reactions in the Krebs cycle
- c. The production of ATP and reduced coenzymes during the cycle
- d. The chemiosmotic production of ATP during electron transport

Conceptual-thematic free-response question about cellular energetics from the 1995 AP biology examination:

Energy transfer occurs in all cellular activities. For three of the following five processes involving energy transfer, explain how each functions in the cell and give an example. Explain how ATP is involved in each example you choose:

- Cellular movement
- Active transport
- Synthesis of molecules
- Chemiosmosis
- Fermentation

AP INSTRUCTION

Little is known, other than anecdotally, about what actually happens in AP classrooms as teachers engage with students in the teaching–learning process. Teachers make decisions every day and in every class period about what to teach and how. Many factors influence these decisions, including teaching philosophies; experience with various teaching strategies; the teacher's own educational background, experience, and familiarity with various topics in the discipline; and student outcomes. In typical honors courses,

teachers generally feel freer to follow their own interests and pursue topics within the broad course outline in which their content knowledge is most secure. In AP courses in which teachers focus on preparing their students for success on an AP examination, there is internal accountability if students take the external examination (Herr, 1993), although little can be said about accountability if large numbers of students in the course do not take the test. Differences among schools also influence how a course is implemented. Scheduling and length of class periods, available facilities and resources, and existing state standards and assessments for courses preceding the AP course all help shape a course differently in each locality.

AP Course Descriptions and Teacher's Guides

AP program materials address instruction only in a very general way. For example, a letter to teachers from Gasper Caperton, President of the College Board, is included as a preface to the May 2002–May 2003 course descriptions for AP biology, calculus, chemistry, and physics. He states, “This AP Course Description provides an outline of content and description of course goals, while still allowing teachers the flexibility to develop their own lesson plans and syllabi, and to bring their individual creativity to the AP classroom.” Consistent with this message, for example, the May 2002–May 2003 AP physics course description features a message from the development committee encouraging the following broad instructional goals (CEEB, 2001d):

- Basic knowledge of the discipline of physics, including phenomenology, theories and techniques, and generalizing principles.
- Ability to ask physical questions and to obtain solutions to physical questions by use of qualitative and quantitative reasoning and by experimental investigation.
- Fostering of important student attributes including appreciation of the physical world and the discipline of physics, curiosity, creativity and reasoned skepticism.
- Understanding connections of physics to other disciplines and to societal issues. (p. 3)

The course descriptions in the other subjects also provide statements of goals and emphases that suggest a focus for instruction, such as the value of active learning, but do not address strategies or specific models for instruction in any detail.

Instructional strategies that might be employed effectively in achieving the instructional goals specified for AP courses may be among the teaching

strategies and techniques included with the sample course outlines presented in the AP teacher's guides. However, the following two examples of strategies provided by teachers in the teacher's guide for AP biology (Schofield, 2000) are indicative of the degree of variability in instruction that might be found in AP biology classrooms:

"The primary goal of the class is to ensure that students leave having experienced an intense course of college-level biology. I do this mainly through lectures and discussions, during which time students are able to ask plenty of questions." (p. 45)

"I try to provide my students with a variety of teaching techniques that encourage both independent and group activities." The strategies described by this teacher include student discussion of journal and newspaper articles, student presentations of course topics, use of computer simulation software and a yearlong independent experimental research project. (pp. 58–59)

The section of the May 2002–May 2003 course description for AP chemistry entitled *A Guide for the Recommended Laboratory Program for Advanced Placement Chemistry* (CEEB, 2001c, pp. 36–51) clearly states goals for the laboratory program that include inquiry and student experimentation:

The program of laboratory investigations should be seen as a cyclic continuum of inquiry rather than a linear sequence of steps with a beginning and an end . . . the ideal program should not only allow students to gain experience with traditional laboratory exercises, . . . but also provide opportunities for students to carry out novel investigations. (CEEB, 2001c, pp. 39–40).

The stated goals for laboratory work (CEEB, 2001c) encourage students to:

- Think analytically and to reduce problems to identifiable, answerable questions.
- Design and carry out experiments that answer questions.
- Draw conclusions and evaluate their validity.
- Propose questions for further study.
- Communicate accurately and meaningfully.

The teacher's guide for AP chemistry (Mullins, 1994) describes a variety of laboratory programs, but does not address the context in which they might be effective in meeting the stated goals. Most of the programs described in the guide are based on typical published manuals for college-level introductory chemistry laboratory programs that prescribe both a purpose and a step-by-step procedure for students and allow few opportunities

for inquiry or student-designed investigations. Some course descriptions include laboratory components that may be more effective in providing these opportunities, including “small-scale inquiry labs” (Mullins, 1994, p. 74) and preparation of a botanically based universal indicator (p. 86).

Similarly, the stated goal for the 12 biology laboratory investigations is to encourage higher-level thinking and provide opportunities for students to learn concepts, acquire skills, and engage in problem solving. The manuals, however, while providing important information to teachers about materials and procedures that are essential features of a biology laboratory program, specify the questions to be investigated, as well as step-by-step procedures. They provide no guidance to teachers about establishing a laboratory program that would enable student inquiry and no support for the goal stated in the AP Biology course description that students gain personal experience in scientific inquiry.

The report from the CFAPP is also relatively silent about instruction. It recommends only that the College Board set high standards for AP course delivery and provide demonstrations via video and other media of “best practice” teaching approaches (CFAPP, 2001, p. 10).

Messages About Instruction Conveyed by AP Examinations

Recent guidelines given to the development committees for AP science courses include a charge to assess knowledge about laboratories and experimentation. One of the free-response questions on each AP science examination will be a laboratory question. The format of the second section of the chemistry examination was changed in 1999 with the introduction of a required laboratory-based question. The 1999 question referred to a traditional experiment designed to determine the molar mass of an unknown gas. Commentary on the question in the 1999 released exam for AP chemistry states that the goal of the question is to determine whether students understand how an experiment works, as well as the chemistry behind it. Students having performed the experiment (or a similar one involving the determination of moles of a gas collected over water) in the laboratory may have had an advantage, as the question asked them to explain the purpose of steps in the experiment and list measurements that must be made. However, the question also could have been answered on the basis of knowledge of variables needed in the calculation, without a student’s having actually completed the laboratory. And although one of the stated goals for the AP chemistry laboratory program is for students to design and carry out experiments, students have not yet been asked to design an experiment on an AP chemistry examination. Thus the program materials may be sending conflicting messages,

since the examination questions indicate that experience with designing experiments is not necessary for success.

AP ASSESSMENT

The AP examinations, administered nationally in May of each year, provide the foundation for curriculum and instruction in AP courses. They are timed examinations, with about 50 percent of the total time devoted to multiple-choice questions and the rest to free-response, essay, or problem-solving questions.⁴ Students can elect to have their examination scores reported to their choice of colleges, where the scores may be considered in decisions about placement in a college course, awarding of credit for the introductory course in the subject, or both (see Chapter 2, this volume).

AP courses are intended to represent general introductory-level college courses. The AP examinations are designed to allow students to demonstrate mastery of the concepts and skills learned in the course, enabling some students to undertake, as freshmen, second-year work in the sequence at their institution or to register for courses in other fields for which the general course is a prerequisite.⁵ Consequently, AP examinations must be valid and reliable measures of student achievement at the college level. “Continued acceptance by colleges and universities of the validity of the content of AP courses, the validity and reliability of the AP Examinations, and the integrity of the scoring process is critical to AP’s success” (CFAPP, 2001, p. 6).

How AP Examinations Are Developed

Content specifications for AP examinations are determined during the development of AP courses. The development committee for each AP course is responsible for deciding the general content of the examination and the ability level to be tested. The examination is constructed using the topic percentages from the AP course descriptions as a guideline for the distribution of questions. The development committee helps write and review test questions, as well as materials (including the AP course descriptions) that

⁴These percentages do not necessarily reflect the weighting of scores as a final examination grade is determined.

⁵The policies of colleges and universities vary widely with respect to the score they will accept to award credit or placement and how that score translates into college credit or placement. Indeed, individual departments within an institution of higher education often have very different policies and expectations. This issue is considered in greater detail in Chapter 2 this volume.

are distributed to schools. The committees also help create and give final approval for each examination.⁶

The committees, representing both secondary- and college/university-level teachers, work closely with ETS content specialists and psychometricians to ensure that the examination scores will mean the same thing to from year to year and from student to student. AP validity studies are designed to validate the use of AP for college credit by measuring the comparability of student knowledge of content and processes with that of students in introductory-level college courses (see Chapter 10, this volume, for a discussion of these studies). Most of the multiple-choice questions are written by committee members and pretested in college classes to obtain some estimate of the degree of difficulty and comparability with college courses. For optimal measurement, the AP development committee endeavors to design a multiple-choice section such that the average raw score is between 40 and 60 percent of the maximum possible raw score. Questions at varying levels of difficulty are included. Using many questions of medium difficulty ensures that clear distinctions will be made between students earning grades of 2 and 3 on the one hand and 3 and 4 on the other (CEEB, 2000b, p. 1). Some previously administered questions are included to link the current form of the examination to previous forms, thus maintaining reliability from year to year and examination to examination. The committees write, select, review, and refine free-response questions. One important aspect of test development is determining which item type and format are best for assessing a given topic or skill area. AP development committee members work with AP content experts and ETS statisticians to make this determination. Free-response questions are designed so that students will have to use analytical and organizational skills to solve problems, predict the products of chemical reactions, and formulate answers to questions (CEEB, 2000b, p. 2). The College Board does not, however, employ systematic research to determine the validity of test items in measuring cognitive processes.⁷

As questions are being written and refined, the development committees propose preliminary scoring standards that are based on consistent criteria from year to year. The committees also develop a formula for assigning composite scores based on differential weights for the multiple-choice and free-response questions.

⁶see <http://www.collegeboard.org/ap/techman/whois/apdevcom.htm> (November 26, 2001).

⁷The committee has been informed that an effort is presently under way by the College Board to begin the collection of validity data.

TABLE 3-2 College Board Recommendations Regarding Students' Qualifications for Receiving College Credit, Placement, or Both

AP Grade	Qualification
5	Extremely well qualified
4	Well qualified
3	Qualified
2	Possibly qualified
1	No recommendation

SOURCES: CEEB (2001a, 2001b, 2001c, 2001d).

How AP Examinations Are Scored

In scoring, the number of correct and incorrect answers in the multiple-choice section of an examination is determined, and a correction for guessing is applied. The procedures for scoring the free-response sections are similar to those used by other testing programs to score essays or constructed-response items. Faculty consultants score the free-response questions during AP readings, which are held at various sites (usually college campuses) throughout the United States each June.⁸ Because it is essential that students' responses be scored consistently, "a great deal of attention is paid to the creation of detailed scoring guidelines, the thorough training of all faculty consultants, and various 'checks and balances' applied throughout the AP Reading."⁹ Composite scores are created using formulas developed by each development committee.

AP uses a five-point scale for awarding final grades on the examinations. The qualification for college credit that is described for each AP grade is shown in Table 3-2. As indicated, those students who earn a score of 3, 4, or 5 are described by the College Board as qualified for credit and/or enrollment in advanced courses at colleges and universities.

Boundaries for awarding AP grades are reset annually at a grade-setting session for each examination. Participants in these sessions usually include the chief faculty consultant, the AP director or associate director from the ETS, the College Board director or associate director of the AP program, ETS content experts for the discipline, and an AP program statistician. Grade distribution charts for each examination are available on the subject pages of the AP Web site.¹⁰

⁸All of the examinations from a subject area are graded at the same site.

⁹See <http://www.collegeboard.org/ap/techman/chap3/scorefc.htm> (February 11, 2002).

¹⁰See <http://apcentral.collegeboard.com/courses/overviews/> (February 11, 2002).

How Examination Results Are Reported

AP grade reports are sent in July to the college(s) designated by the student, to the student's secondary school, and to the student. The report includes the grade earned and an interpretation of that grade for each AP exam taken by the student in the current year. A report to AP teachers is sent for each examination taken by five or more students at participating schools. The report compares these students' performance with that of the national candidate group. Mean scores for the multiple-choice questions grouped by four or five major topics and for each free-response section are compared. The free-response booklets of a school's senior AP students are released to the schools after October 15 of the year in which the exam is taken if the booklets have not already been requested by a postsecondary institution.

The free-response questions on the AP examinations are released to students and teachers after the exam has been administered. They are also posted on the AP Web site, along with scoring guidelines and student samples with scoring commentary, after the examinations have been graded.

Entire released examinations, including both the multiple-choice and free-response sections, are published about every 5 years for each subject.¹¹ The publication provides the following:

- Multiple-choice questions and answer key, and the percentage of candidates who answered each question correctly.
- Free-response questions and scoring guidelines.
- Sample student responses with commentary (the actual scores these students received, with a brief explanation).
- Statistical information about students' performance on the examination.

How the College Board Determines Whether AP Examinations Accomplish Their Purpose

AP examinations must be valid and reliable measures of students' achievement at the college level. Colleges need to know that the AP grades they receive for their incoming students represent a level of achievement equivalent to that of students who take the corresponding introductory course in college. The College Board conducts college comparability studies to confirm that the AP grade scale is properly aligned with current college standards. Periodically, instructors from some of the 200 colleges receiving the largest number of AP grades for an examination administer the AP examina-

¹¹Free-response questions are released annually.

tion or portions thereof to college students who are completing the corresponding college course. The performance of the college students on the examination is compared with that of the AP students. When AP grades are set, the composite score cut points are established so that the lowest composite score for a grade of 5 is roughly equal to the average composite score of college students earning a grade of A. The lowest composite score for a grade of 4 is roughly equal to the average composite score for students with a grade of B. The average composite score of students receiving a grade of C is used to set the lowest AP grade of 3. Similar logic is used in setting the lowest composite score for a grade of 2 (Morgan and Ramist, 1998).

AP PROFESSIONAL DEVELOPMENT

What Is Known About the Preparation and Credentials of AP Teachers

Very little is known about the teaching experiences and preparation of teachers who are teaching AP courses. The College Board is currently conducting a survey of AP teachers with the goal of describing their characteristics and identifying teacher attributes that affect the success of students.¹² Until the results of this study are available, information about the teachers involved with the AP program must be based on descriptions provided in program materials.

The College Board (CFAPP, 2001, p. 6) states, “AP is an enterprise that relies on a culture of dedication, volunteerism, and altruism among AP teachers.” The College Board (CFAPP, 2001, p. 2) estimates that there were approximately 100,000 teachers teaching AP classes in the United States during the 1999–2000 school year. Assigning teachers to AP courses is usually a school-level decision; the College Board does not certify teachers and has relatively little to say about the matter of teacher qualifications. School administrators attending an AP workshop reported that arbitrary assignment of teachers to AP courses is used only when absolutely necessary and that in many cases, teachers apply specifically to take an AP assignment (Burton, Bruschi, Kindig, and Courtney, 2000).

Professional Development Experiences of AP Teachers

Although the College Board does not require participation in AP professional development activities, each of the AP teacher’s guides encourages such participation. Stipends and travel support may come from local schools

¹²See <http://www.collegeboard.org/ap/research/abstract24.html> (February 11, 2002).

or school districts or from the states and the federal government, or a teacher may receive no support at all. Consequently, many of the teachers who participate in AP professional development activities do so on their own time and at their own expense.

The two principal types of professional development available to AP teachers nationally are 1- and 2-day AP workshops offered by the College Board's regional offices and AP summer institutes, usually 5 days long and offered by a variety of independent agencies. During the 1999–2000 academic year, more than 56,000 AP teachers (about 56 percent of the approximately 100,000 teachers teaching AP classes in the various disciplines) participated in professional development workshops and summer institutes (CFAPP, 2001, p. 2). Teachers who participate may have widely differing professional development experiences, depending on which workshop or summer institute they attend. Recognizing the variability in content and uneven quality of the workshops and summer institutes, the College Board recently developed and implemented quality standards for AP workshop consultants and AP summer institutes (College Board, 2000, 2001).

Generally, teachers, guidance counselors, and school administrators attend the 1- or 2-day workshops to learn the rudiments of teaching an AP course and to be apprised of the latest developments and expectations for each course. Major topics covered include the following:

- Advice on preparing students for the AP examinations.
- Practical information on starting or revising an AP course.
- Insights into the structure, content, and grading of the AP examinations.
- New technology applications.
- Updates from the College Board and the ETS.

AP teachers attending the summer institutes explore a variety of instructional strategies that can be employed both to help their students learn and understand the material and to prepare them for success on the national examination. The strategies discussed range from covering every topic to emphasizing concepts, principles, and a “scientific attitude,” and from teacher-centered, content-based lecture delivery to a variety of student-centered pedagogies (Burton et al., 2000). AP science teachers attending summer institutes often perform and discuss laboratory activities with the guidance of experienced AP instructors. They follow actual laboratory procedures; learn to handle equipment and materials; and discuss time frames, pitfalls, possible shortcuts, reasonable laboratory results, good follow-up questions, and ways of integrating the laboratory experience most profitably into the classroom setting (Schofield, 2000, p. 13). Fifty summer institutes responded to a 1999 survey in which directors were asked to provide evaluation data

about their workshops. Workshop participants from these 50 programs indicated that sharing ideas and experiences, networking, and having good discussions with other teachers were of the activities of most value to them. Many of the participating AP teachers reported feeling isolated and unsupported after they left the institutes and workshops, as most of them returned to schools where they were the only AP teacher in a discipline (Burton et al., 2000).

Experienced AP teachers often cite the experience of serving as a faculty consultant for the annual AP reading as a highly valued professional development experience. In June 2000, approximately 5,000 college faculty and high school teachers participated in the 1-week sessions. The College Board cites three of the most common reasons given by readers for applying to return after their first experience:¹³

- High school and college faculty exchange ideas on an equal playing field.
- Networks are established among participants.
- Practice gained in establishing and applying rubrics makes participants better teachers.

The CFAPP recommends that teacher professional development become the area of greatest emphasis for technological investment and development: “Technology can supplement face-to-face workshops and institutes, providing ongoing support to teachers throughout the year” (CFAPP, 2001, p. 11). Services currently provided to teachers by the College Board include an AP electronic mailing list for each discipline—*AP Central*; the College Board’s online site for the AP program, with information about AP courses, publications, workshops, and summer institutes; and videoconferences with the teachers who develop the AP courses and examinations. The College Board presents no information about local professional development activities available for AP teachers, but AP teacher’s guides for the individual disciplines refer teachers to their respective professional organizations, which often sponsor sessions on AP at state and national conventions.

The CFAPP report warns that the current models for AP professional development are and will continue to be insufficient. An estimated 100,000 new AP teachers will be needed between now and the end of the decade, and many of them will be teaching AP for the first time. The commission states: “The College Board, working in cooperation with schools, school systems, colleges and universities, governments and others, must make an unconditional commitment to teacher professional development. Without

¹³See <http://www.collegeboard.org/ap/readers/index.html> (November 26, 2001).

this commitment, access to AP will not improve and quality will decline” (CFAPP, 2001, p. 10). Specific recommendations include (1) developing and implementing a mentoring system using experienced and retired AP teachers as mentors, (2) identifying successful strategies for preparing teachers to teach AP, and (3) evaluating and incorporating new models of professional development that support instructional and curricular changes. The commission also recommends that the College Board expand the development and implementation of the AP Vertical Teams program. This program focuses on collaborative planning workshops at which teachers in grades 7–12 are involved in redesigning middle school and high school curricula to give students good preparation for AP and other advanced courses.

4

The International Baccalaureate Programme

Given the differences in their origins and goals, it is not surprising that the International Baccalaureate (IB) and Advanced Placement (AP) programs differ significantly. This chapter presents a detailed review of the IB program; a similar review of the AP program is provided in Chapter 3. The first section gives an overview of the IB program; the sections that follow address in turn IB curriculum, instruction, assessment, and professional development.

OVERVIEW

The International Baccalaureate Organisation (IBO), a nonprofit educational foundation headquartered in Geneva, Switzerland, was founded in the 1960s with the mission of fostering in member schools international understanding and responsible world citizenship, as well as intellectual rigor and high academic achievement (IBO, 1997a). The IB Diploma Programme consists of a comprehensive precollege curriculum for highly motivated students in the last 2 years of high school that allows students to fulfill the requirements of various educational systems and aims to incorporate the best elements of many different national models (IBO, 1997a). Each of the IB courses in mathematics and the experimental sciences incorporates a formative internal assessment component and culminates in an internationally administered external examination. Students who complete the program and receive qualifying scores on the examinations are awarded the IB Diploma.¹

¹Although the IBO does not represent its courses as replacements for college courses, some college and university policies allow for granting credit or placement. A database listing these institutions and describing their policies can be accessed at the IBO Web site at <http://www.ibo.org/ibo/index.cfm/en/ibo/services/universities> (November 28, 2001).

The requirements for the IB Diploma are designed to engage students in an integrated program of studies as they complete courses and examinations in one subject from each of six different subject groups.² Students study some subjects in depth by selecting at least three but no more than four courses at the Higher Level (HL) and explore others more broadly at the Standard Level (SL). This approach represents a deliberate compromise between the early specialization preferred in some national systems and the breadth found in others (IBO, 1998b, p. 2, 2001a, 2001b, 2001c, p. 1). HL courses are 2-year courses. SL courses may be completed in 1 year if scheduling allows for the required number of hours, although many IB schools offer 2-year SL courses.³

In contrast to the AP program, which aims to provide discrete college-level courses for students in high school, the IB courses are part of an integrated program designed to prepare students for college. The IB mathematics program offers a selection of mathematics courses designed to meet the varying needs, interests, and abilities of college-bound high school students. The IB Mathematical Methods SL course is designed to provide a sound mathematical background for students who expect to study subjects at the university level that have a significant mathematical content. The IB Mathematics HL and Further Mathematics SL courses offer more rigorous preparation. Another fundamental difference between the AP and IB mathematics programs is that the IB mathematics courses are not calculus courses; rather, they focus on many advanced mathematics topics that may include calculus.⁴ Similarly, students are offered both HL and SL courses in each of the experimental sciences; this accommodates students with a strong interest in science while also providing sound preparation in science for those who wish to focus on other subjects.

Three additional requirements are designed to give IB Diploma candidates the opportunity to pursue their own interests while at the same time developing a broad understanding of the bases of knowledge in both the humanities and the sciences. Theory of Knowledge is a 2-year course of study unique to IB and mandatory for every diploma candidate. "It challenges students and their teachers to reflect critically on diverse ways of knowing and areas of knowledge, and to consider the role which knowledge plays in a global society. It encourages students to become aware of

²Language (a student's first language and a study of world literature), a second modern language, the social sciences, the experimental sciences, mathematics, and the arts and electives.

³For IB courses, 240 hours of teaching is recommended for HL courses and 150 hours for SL courses.

⁴For a detailed discussion of the content of these courses, including their calculus component, and an analysis of how they fit into typical U.S. high school mathematics programs, see the report of the mathematics panel, available at <http://www.nap.edu/catalog/10129>.

themselves as thinkers . . .” (IBO, 2000b, p. 3). The curriculum for the course centers on a series of questions, including those designed to help students understand the nature of knowledge in mathematics and the sciences.⁵

IB Diploma candidates must also satisfy the Extended Essay requirement by undertaking original research and writing an essay of some 4000 words. This requirement offers students the opportunity to investigate a topic of special interest and acquaints them with the independent research and writing skills expected at the university level. It allows them to deepen their study by investigating a topic that was introduced in one of their higher-level courses or to add breadth to their program by studying a subject not included in their diploma courses. A third requirement—the Creativity, Action, and Service requirement (CAS)—encourages students to become involved in extracurricular activities.

A student who satisfies the Theory of Knowledge, Extended Essay, and CAS requirements and achieves a cumulative score of at least 24 points on the six examinations (each of which is graded on a scale from 1 to 7) is awarded the IB Diploma. An IB Certificate is awarded to students who take any number of individual IB courses and the subsequent examinations, but do not fulfill all of the requirements for the diploma.

During the past three decades, an increasing number of U.S. high schools have joined IB schools worldwide in offering the Diploma Programme. In May 2000, 18,511 students from 255 U.S. public and private schools took 50,745 IB examinations. Approximately two-thirds of those students were candidates for the IB Diploma,⁶ and one-third were certificate candidates (May 2000 Summary). Although these students represent less than 2 percent of U.S. high schools, their increasing numbers indicate that the IB program is experiencing a period of rapid growth in this country. The number of IB examinations administered in the United States has increased by an average 16 percent annually every year since 1994. The number of schools applying to International Baccalaureate of North America (IBNA) has tripled over the

⁵The central questions examined include the following: How do I or how do we know that a given assertion is true, or a given judgment is well grounded? How is knowledge gained? What role does personal experience play? Do we construct reality, or do we recognize it? How is a mathematical proof different from, or similar to, justifications accepted in other areas of knowledge? Has technology, for example computers and electronic calculators, influenced the knowledge claims made in mathematics? Is the scientific method a product of western culture or is it universal? To what extent can science be understood through the study of just one discipline, for example physics? Are the models and theories created by scientists accurate descriptions of the natural world, or are they primarily useful interpretations for prediction, explanation, and control of the natural world? (IBO, 2000b, pp. 3–4)

⁶According to Paul Campbell, director for programs, International Baccalaureate of North America (IBNA) (personal communication), approximately 70 percent of diploma candidates earn the IB Diploma.

past several years and has been stable recently at 50 to 60 applications per year.⁷

A high school must offer all the components of the diploma program and be authorized by the IBO to use IB curriculum and assessment materials, register candidates for the IB examinations, and qualify them for the IB Diploma. U.S. schools that are interested in joining the IBO complete a self-study and submit a formal application to IBNA. Receipt of the application is followed by an on-site visit by representatives from IBNA that focuses on evaluating faculty commitment and qualifications; physical facilities, including the library and science laboratories; and commitment at the school level. The process of becoming an IB school can take 2 years or more as IBNA evaluates the ability of both the school and the school district to commit resources to providing the administrative structure, faculty, and facilities needed to support the offering of the IB Diploma Programme. IBNA maintains a relationship with member schools that includes monitoring test registration and administration.⁸ Every 5 years, each IB school conducts a self-evaluation and submits a school review to IBNA.

IB CURRICULUM

IB mathematics and science courses are designed to be components of an integrated program, and this objective is reflected in the curriculum materials. The IB program guides for courses in each discipline, including mathematics and the experimental sciences, present common aims and objectives. A discussion of the program model, a description of the examination, and detailed information and guidance for teachers about meeting the internal assessment requirements are common to all of the subject guides for experimental science. The guides also provide a topic outline and a detailed syllabus for each course. Teachers use the guides as the basis for determining the structure of their curriculum. Thus like the curriculum for AP courses, the curriculum for IB courses, as it is designed and implemented, can vary from school to school in sequence and emphasis. However, the specificity of the IB syllabus and the requirements for the IB internal assessment lead to less variability in the content of the curriculum and the nature of the laboratory and other practical experiences provided to students than is the case in the corresponding AP courses. The extent to which the IBO specifies curriculum for IB courses is described in detail in the discussion that follows.

⁷Paul Campbell, director of programs, IBNA (personal communication).

⁸Schools are not able to maintain membership in the IBO without registering students in IB courses for the examinations and ensuring the security of the examinations.

Development of IB Courses

The IB course development process is guided by the IBO's vision of a rigorous, comprehensive, and balanced college preparatory curriculum. A curriculum review committee with international membership is responsible for articulating, implementing, and maintaining the vision in each subject area. The International Baccalaureate Curriculum and Assessment Centre (IBCA) in Cardiff, Wales, has primary responsibility for curriculum development. IBCA staff representatives, most of whom are former IB teachers, work with teachers representing IB schools from around the world on the curriculum review committees. The committees for all subjects in a discipline convene jointly at IBCA because changes in the mathematics or experimental sciences programs impact all of the subjects in that discipline. The role of the curriculum review committees encompasses identifying topics to be included, as well as reviewing the assessment structure and writing the assessment statements for each topic. The mathematics curriculum review committees are also responsible for specifying presumed knowledge and skills for each IB mathematics course.

An important distinguishing feature of IB curriculum review is the systematic involvement of classroom teachers in a "consultative process" (IBO, 1999d). The recent revision of the IB Experimental Sciences curriculum illustrates the process well. The process began with a review of responses to questionnaires sent to each IB biology, chemistry, and physics teacher. Teachers were asked about the instructional time spent on each topic in the syllabus and on laboratory work for each topic, as well as about the technology resources available to them. The biology, chemistry, and physics curriculum committees then made revisions to the diploma guides for each subject. Revised versions of the guides were posted on a password-protected Web site for further teacher review and comment before being published.

Content of IB Courses

The *IB Diploma Programme Guide* for each subject includes a detailed topic outline. It provides IB teachers with some guidance in identifying fundamental concepts by grouping "essential principles of the subject" in material designated as the core.⁹ The core topics are common to both the SL and HL courses in a subject, with additional topics being specified for the latter.

⁹In the experimental sciences, 80 hours of instruction is recommended for core material in SL courses, with an additional 55 hours for HL courses. In mathematics courses, 105 hours is recommended for SL and 195 hours for HL courses.

The guides also provide outlines for optional topics.¹⁰ Teachers of each IB experimental science subject at an IB school must collaboratively select two *options* to include in their curriculum. Options are generally selected on the basis of teachers' backgrounds and areas of expertise, as well as available local resources. The options for IB mathematics courses allow for studying a topic in more depth. Teachers select one option, and the selection made can determine the nature of the course, resulting in very different experiences for students. In the United States, for example, the Mathematics Methods SL option Further Calculus is often selected over the other two options—Statistical Methods and Further Geometry—to provide students with a course that is comparable to the AP Calculus AB course. The experimental science courses offer options that allow in-depth study of a topic, such as the physics options Astrophysics and Relativity. Many, like the physics option Biomedical Physics, focus on interdisciplinary topics. Schools are also allowed to submit an option of their own design for approval. That some schools have taken advantage of this opportunity is indicated by the addition of Medicine and Drugs, previously a local option, to the most recent revision of the IB program guide for chemistry.

The IB program guides provide considerable information about what students are expected to know by specifying *assessment statements*, expressed in terms of *learning outcomes*, for each topic in the experimental science courses. The guides also give estimated teaching hours for each topic, but do not recommend a sequence for the presentation of topics. To illustrate the considerably greater detail provided in the IB guides than in the AP course descriptions, the treatment of ionic bonds in IB chemistry can be contrasted with the AP topic outline for Chemical Bonding included in Chapter 3, this volume. The latter outline simply lists “ionic” as one of the binding forces that might appear on the AP chemistry examination. AP chemistry teachers must infer the desired depth of treatment of the topic by reviewing old examination questions. In contrast, the *Programme Guide for IB Chemistry* (IBO, 2001b, p. 51) gives the following six assessment statements for the same topic:

Topic 4: Bonding

4.1 Ionic Bond (2 hours)

- 4.1.1 **Describe** the ionic bond as the result of electron transfer leading to attraction between oppositely charged ions.
- 4.1.2 **Determine** which ions will be formed when metals in groups 1, 2, and 3 lose electrons.

¹⁰Mathematics courses include one 35-hour option. Experimental science courses include two options—15 hours each in SL courses and 22 hours each in HL courses.

- 4.1.3 **Determine** which ions will be formed when elements in groups 6 and 7 gain electrons.
- 4.1.4 **State** that transition metals can form more than one ion. Restrict examples to simple ions e.g., Fe^{2+} and Fe^{3+} .
- 4.1.5 **Predict** whether a compound of two elements would be mainly ionic or mainly covalent from the position of the elements in the periodic table, or from their electronegativity values.
- 4.1.6 **Deduce** the formula and **state** the name of an ionic compound formed from a group 1, 2, or 3 metal and a group 5, 6, or 7 non-metal.

The assessment statements for experimental science use 26 action verbs to indicate expectations for each topic. Some of these verbs are highlighted in bold in the preceding example (“describe,” “determine,” “state,” “predict,” and “deduce”). The guides define each verb and associate it consistently throughout the syllabus and on the IB examinations with one of three content objectives:

- Demonstrate an understanding.
- Apply and use.
- Construct, analyze, and evaluate.

Use of the action verbs conveys important information to teachers about the expectations for depth and breadth of content. Teachers and students are expected to be familiar with the definitions of these verbs. They must be aware that, for example, “predict” and “deduce” are associated with the third objective (construct, analyze, and evaluate) and require deeper understanding than “state,” which is associated with the first objective (demonstrate an understanding) and requires only memorization.

Laboratory Requirement for IB Experimental Sciences Courses

The IB program has more to say about laboratory experimentation than does the AP program, as the score for a student’s laboratory work (assessed internally by the teacher and moderated externally by the IBO) makes up 24 percent of a student’s final examination score. The program guides do not recommend any specific laboratory exercises, but provide general guidance for the design of a laboratory program. The *Vade Mecum: Procedures Manual for IB Coordinators and Teachers* specifies that the laboratory activities in IB Experimental Sciences courses must include hands-on investigations in the

TABLE 4-1 Summary of Eight *Assessment Criteria* for IB Experimental Sciences and Two or Three *Aspects* of Each Criterion

Assessment Criteria	Aspects
Planning (a)	Defining the problem or research question; formulating a hypothesis or prediction; selecting variables.
Planning (b)	Selecting appropriate apparatus or materials; designing a method for the control of variables; designing a method for the collection of sufficient relevant data.
Data collection	Collecting and recording raw data; organizing and presenting raw data.
Data processing and presentation	Processing raw data; presenting processed data.
Conclusion and evaluation	Drawing conclusions; evaluating procedure(s) and results; improving the investigation.
Manipulative skills	Carrying out techniques safely; following a variety of instructions.
Personal skills (a)	Working within a team; recognizing the contributions of others; exchanging and integrating ideas.
Personal skills (b)	Approaching scientific investigations with self-motivation and perseverance; working in an ethical manner; paying attention to environmental impact.

SOURCES: Adapted from IBO (2001a, 2001b, 2001c).

laboratory or in the field, as well as problem-solving activities involving data analysis (IBO, 2000d, p. 4). At least 25 percent of the teaching program (not including time spent writing up the experiments) must be devoted to the Practical Scheme of Work (PSOW, described in greater detail below).¹¹ Teachers are provided extensive detail about the criteria for the internal assessment of laboratory work, as they must offer opportunities for their students that match the relevant assessment criteria. Specific criteria for the internal assessment guide science teachers in setting the stage for students to design and carry out their own experiments.

The IB internal assessment for the experimental sciences uses eight assessment criteria to evaluate the work of both HL and SL candidates (Table 4-1). These are described in the guide for each of the IB experimental sciences courses. For a particular criterion, a student's laboratory work is judged to see whether the requirements for different aspects of the criterion have been fulfilled completely, partially, or not at all. For example, forming a hypothesis is one of the three aspects of the planning (a) criterion. The following example (Table 4-2) is given in the guide for each of the IB experimental sciences courses.

¹¹At least 60 hours for HL students and 40 hours for SL students (IBO, 2000d, p. 3), which includes 10–15 hours that candidates must spend on their Group 4 project (IBO, 2000c, p. 3).

TABLE 4-2 Example of Expectations of Students to Meet the Requirements of One Aspect of the Planning (a) Criterion

Formulating a Hypothesis or Prediction		
Complete	Partial	Not at all
Relates the hypothesis or prediction directly to the research question and explains it, quantitatively where appropriate.	States the hypothesis or prediction but does not explain it.	Does not state a hypothesis or prediction.

SOURCES: Adapted from IBO (2001a, 2001b, 2001c).

The guides also provide a discussion of the criteria to guide teachers. “It is generally not appropriate to assess planning (a) for most experiments or investigations found in standard textbooks, unless the experiments are modified. It is essential that students be given an open-ended problem to investigate” (IBO, 2001a, 2001b, 2001c, p. 24). A separate publication, *Teacher Support Material: Experimental Sciences—Internal Assessment* (IBO, 1999e), provides teachers with exemplars of student laboratory reports that fulfill all aspects of the criteria completely, as well as examples of those that do not.

Teachers of the various experimental science subjects in an IB school must jointly submit to the IBO a PSOW, a summary of all the investigative activities their students carry out. Each PSOW must include at least a few complex investigations that make greater demands on the students than those posed by simple experiments. It must also include the date and a brief description of each investigation and an estimate of the time spent. The PSOW is accompanied by a copy of the instructions given to students for each activity. A script of any verbal instructions offered also must be included. These materials are used in moderating the internal assessment grades to ensure, for example, that if students are offered credit for planning, the teacher has not given them procedures. “The main criticism made by moderators was that the investigations were too directed with no real freedom for the candidates to develop the investigation for themselves” (IBO, 1998a). The PSOW also must include an interdisciplinary project involving all of the IB science students at a school in identifying and investigating an issue of local interest. The project requirements emphasize sharing of concepts and theories from across the disciplines, as well as the processes involved in scientific investigation, rather than products.

The PSOW is evaluated yearly, and teachers receive feedback and suggestions for improvement. More detail about the scoring and moderation of the internal assessment and about the feedback the IBO provides to schools on their laboratory programs is provided later in this chapter.

IB INSTRUCTION

There is variation from classroom to classroom in what is actually taught in an IB course, how much of the topic outline is covered, how much time is devoted to different topics, and what instructional strategies are used. However, the detail provided in the IB guides regarding expected student outcomes directs teachers toward the use of specific instructional strategies. Teachers are told that internal assessment tasks should be built into classroom teaching whenever possible. Internal assessments should form part of the learning experience of the students and should not be seen as an addition to the teaching schedule (IBO, 1999b).

IB Programme Guides and Teaching Notes

IB mathematics programme guides provide general guidance on instruction, but also offer specific suggestions about instructional strategies. The objectives for students given in the mathematics program guides include the following:

- Organize and present data in graphic, tabular, and/or diagrammatic form.
- Formulate a mathematical argument, and communicate it clearly.
- Recognize patterns and structures in a variety of situations.
- Use appropriate technological devices as mathematical tools.

Teaching notes for each topic in the syllabus for each mathematics course provide suggestions for teachers, while stating that “it is not mandatory that these suggestions be followed” (IBO, 1998b, p. 9). The following are examples of alternative strategies presented in the teaching notes for the Mathematical Methods SL guide: “an informal investigative/experimental approach to statistical inference is envisaged” (IBO, 1997b, p. 21), and “problems might be best solved with the aid of a Venn diagram or tree diagram, without the explicit use of these formulae” (IBO, 1997b, p. 18). The teaching notes also include suggestions for linking content to help students see connections, such as linking the study of the second derivative in the Further Calculus option to the study of exponents and logarithms in the core content (IBO, 1997b, p. 23).

The experimental sciences guides do not address instruction directly, other than to indicate consistently that there is no single best approach to teaching IB courses and that teachers should provide a variety of ways of acquiring information that can be accepted or rejected by each student, allowing different routes through the material (IBO, 2001a, 2001b, 2001c, p. 11). The IB program guide for chemistry tells chemistry teachers, for ex-

ample, that the “chemistry course includes the essential principles of the subject but also, through selection of options, allows teachers some flexibility to tailor the course to meet the needs of their students” (IBO, 2001b, p. 35). References to instruction also appear in annual subject reports, such as the following example from the 1999 IB chemistry subject report (IBO, 2000a):

The main areas of weakness involved applications of principles to specific situations. This process is always a challenge to students. Students need to be exposed repeatedly to the application of basic concepts to new situations. This can be done through examples used in the classroom, by homework assignments which provide a variety of appropriate situations requiring skills beyond recall of information, and by tests and examinations which use questions similar to those used in the IB examination. (p. 401)

As indicated in the discussion of curriculum, the use of action verbs in the experimental science assessment statements informs teachers about the depth of treatment required. Teachers then make decisions about the best way to prepare their students for the required outcomes. For example, “describe the ionic bond as the result of electron transfer leading to attraction between oppositely charged ions” (IBO, 2001b, p. 51) means students must be able to recall the definition of ionic bond. Teachers then make individual instructional decisions about the most effective ways to help their students learn this information. At a level requiring deeper understanding, the ability to “predict molecular polarity based on bond polarity and molecular shape” (IBO, 2001b, p. 52) is an outcome that cannot be achieved by memorizing a breadth of detail, but only by building the necessary understanding during a variety of practical experiences with molecular shapes, bond character, and electronegativities. Teachers must decide how best to accomplish this and are guided by the assessment statement to set up a variety of situations in which students can build understanding and experience.

Messages About Instruction Conveyed by IB Examinations

In specifying aspects of a subject to be assessed, the IB internal assessment criteria require that teachers structure the classroom and laboratory environment so that students have the opportunity to acquire and develop the skills to be evaluated.

IB mathematics teachers are encouraged to integrate the internal assessment assignments for the mathematics portfolio into their teaching. Related teaching and learning strategies discussed in the Mathematical Methods SL guide (IBO, 1997b, p. 51) include the following:

Candidates need to be provided with the opportunities to experiment, explore, make conjectures and ask questions. Ideally, the atmosphere in the classroom should be one of enquiry.

Small groups could work through some relatively simple assignments in order to learn skills associated with portfolio activities.

Students may be unaware of certain strategies associated with experimentation, or “playing,” which are an important part of investigative work, particularly if they have only experienced more formal modes of working.

Similarly, IB experimental science teachers are given guidance in providing a variety of practical experiences for their students. Sample laboratory investigations are offered and analyzed in the IB *Teacher Support Material: Experimental Sciences—Internal Assessment* (IBO, 1999e). The program guides provide direction for preparing students for experimentation without specifying laboratory activities. For example, “the teacher might present the aim of an investigation generally in the form ‘investigate the factors that affect X.’ Students should be able to realize that certain factors will influence X and clearly . . . identify a focused research question” (IBO, 1999e, p. 4). The criteria for personal skills (a) require that a teacher assess a student’s work within a team, defined as follows: “Teams, whose members collaborate, can be formed with a wide variety of people. The views of all team members are respected and actively sought” (IBO, 1998a). Teachers must therefore provide opportunities for students to learn how to work effectively in teams. Teachers are encouraged to use the online curriculum center to share ideas about possible investigations and add resources to the relevant sections of the online subject guides.

IB ASSESSMENT

Assessment in IB mathematics and science courses has two components—external and internal. The external assessment consists of a written examination that is administered internationally over a period of 2 days in May of each year (in November for split-session schools). The examination tests knowledge of both the core and optional topics. The internal assessment component comprises the teacher’s formative assessment of students’ practical work (laboratory investigations in science courses and portfolios in mathematics courses) judged against established assessment criteria. This component is conducted by teachers within the school environment and is moderated externally by the IBO. In the experimental sciences, the external and internal assessments make up 76 percent and 24 percent of the final examination mark, respectively. IB teachers submit internal assessment marks and a predicted final examination grade for each of their students. The latter is the teacher’s prediction of the grade the candidate will achieve in the

subject, based on all the evidence of a candidate's work and the teacher's knowledge of IB standards (IBO, 2000d, p. F14).

The IB assessments are designed to gauge the educational achievement of candidates against the range of objectives specified for each subject. The structure of each written external examination paper "allows candidates to demonstrate their achievement in terms of content knowledge, depth of understanding and use of specific higher level cognitive skills, as described by the subject objectives."¹²

The internal assessment component addresses skills that cannot be demonstrated satisfactorily within the context of a written examination. As stated in the guides, the purpose of the internal assessment for the IB mathematics portfolio is to "provide candidates with opportunities to be rewarded for mathematics carried out under ordinary conditions, that is, without the time limitations and stress associated with written examinations" (IBO, 1998b, p. 47). The requirements for the internal assessment in the experimental sciences are focused on the candidates' skills in laboratory investigation, including planning; data collection and processing; evaluation of procedures and results; manipulative skills; and personal skills, including working with a team (IBO, 2001a, 2001b, 2001c, pp. 20–22).

How IB Assessments Are Developed

Examinations for each IB course are written by chief examiners and deputies and are overseen and approved by the examination board at IBCA. Teams of experienced senior examiners prepare the examinations for each administration in a process that is coordinated and overseen by IBO academic staff. Separate examinations are developed for SL and HL courses in a subject area. Single senior examiners normally write individual examination questions, which are directly linked throughout the examination development process to the assessment statements and the objectives to be measured as outlined in the program guides for each subject. "The questions are not field tested, partly because it is difficult to find a suitable trial group of candidates without the possibility of compromising security. New questions are written for each examination session—they are not banked." Moreover, "for each session, the senior examining team aims to prepare a different form of the examination which is of the same standard of demand as in previous sessions. In practice it is very difficult to achieve a high level of precision."¹³

The IBO also does not calculate the internal reliability of the examina-

¹²George Pook, assessment director, IBCA (personal communication, May 31, 2001).

¹³George Pook, assessment director, IBCA (personal communication, May 31, 2001).

tions, as it is not one of the assumptions of IB assessment that all the items in each written examination paper will assess the same trait. Thus, high correlation of a candidate's performance on different parts of the assessment is not expected. Like the College Board, the IBO does not make use of systematic validity research regarding the cognitive characteristics of its examinations.

As part of the curriculum development and review process in each subject, the IB curriculum committees specify and describe the internal assessment criteria. The examiners in each subject meet to develop common understandings about how to assess each of the criteria. The IBO communicates the assessment details to classroom teachers and moderators in each subject through program materials and workshops.

The assessment structure for each subject is reviewed periodically as part of an overall curriculum review. Proposals for revisions to the assessments are developed by the curriculum review committees through a process similar to that described for curriculum review. The proposals are then reviewed by the Diploma Review Committee, which consists of chief examiners representing each subject group and senior academic staff from the IBO.

After each examination session, candidates' responses are scrutinized closely to determine whether they are in line with expectations for each question. Additionally, all IB teachers are asked to complete feedback forms following the examinations, answering questions about both the emphases of the examination and the content and form of individual questions. Much attention is paid to teachers' comments about the suitability of examination papers in achieving the intended objectives. Information gained in this manner is fed into the examination development process for future sessions.

How IB Assessments Are Scored

The IB grading system is criterion referenced. Each student's performance is measured against seven grade descriptors, given in the form of levels of performance that candidates should be able to demonstrate. The different levels of performance are closely related to the course objectives and are clearly specified for mathematics and the experimental sciences. The descriptors are equally applicable to both HL and SL examinations. As an example, grade descriptors 7, 4, and 1 for the experimental sciences follow (IBO, 1999c):

Grade 7 Excellent performance

Displays comprehensive knowledge of factual information in the syllabus and a thorough command of concepts and principles. Selects and applies relevant information in a wide variety of contexts. Analyzes and evaluates

data thoroughly. Constructs detailed explanations of complex phenomena and makes appropriate predictions. Solves most quantitative and/or qualitative problems proficiently. Communicates logically and concisely using appropriate terminology and conventions. Shows insight or originality. Demonstrates personal skills, perseverance and responsibility in a wide variety of investigative activities in a very consistent manner. Works very well within a team, and approaches investigations in an ethical manner, paying full attention to environmental impact. Displays competence in a wide range of investigative techniques, paying considerable attention to safety, and is fully capable of working independently.

Grade 4 Satisfactory performance

Displays reasonable knowledge of factual information in the syllabus, though possibly with some gaps. Shows adequate comprehension of most concepts and principles but with limited ability to apply them. Demonstrates some analysis or evaluation of quantitative and qualitative data. Solves basic or routine problems but shows limited ability to deal with new or difficult situations. Communicates adequately but responses may lack clarity and include some repetitive or irrelevant material. Demonstrates personal skills, perseverance and responsibility in some investigative activities, although displays some inconsistency. Works within a team and generally approaches investigations in an ethical manner, with some attention to environmental impact. Displays competence in a range of investigative techniques, paying some attention to safety, although requiring some close supervision.

Grade 1 Very poor performance

Recalls fragments of factual information and shows very little understanding of any concepts or principles. Rarely demonstrates personal skills, perseverance or responsibility in investigative activities. Does not work within a team. Rarely approaches investigations in an ethical manner, or shows awareness of the environmental impact. Displays little competence in investigative techniques, generally pays no attention to safety, and requires constant supervision (IBO, 1999c).

The senior evaluating team uses these descriptors when determining the examination marks, which reflect the combined raw scores for the written examinations and the internal assessments. Examiners look to assign candidates the grade that matches their performance most comprehensively by determining the various grade boundaries for the raw scores the candidates achieve. Each time the examinations are administered and marked, the senior examiners meet to decide what marks equate to the same level of performance as in previous sessions.

The process begins by using the grade boundaries suggested by examiners on the basis of their reading of student responses on the written examination. Individual examiners mark students' responses on the examinations

using a set of assessment criteria or mark schemes, which are accompanied by notes about the range of content that might be expected. Scripts with raw scores just below or above the proposed boundaries are reread carefully and evaluated with reference to the criteria described above. Inter-examiner reliability is ensured by a system of moderation in which each examiner sends a sample of his or her marking to a more senior examiner for checking. If the senior examiner's remarking of the sample indicates a slight disparity in standards, a statistical adjustment based on linear regression is made to all of the assistant examiner's marks. If there is substantial disagreement or inconsistency, all of the assistant examiner's work is remarked. Analysis of these moderation samples indicates that in the vast majority of cases, different examiners' marks are within 5 percent of each other, and that in very few cases is the difference more than 10 percent.¹⁴

Schools submit marks for internal assessment to IBCA by a given deadline in April of each year. A moderation process is also used to ensure reliability and an equivalent standard among schools for the internal assessment marks in both mathematics and the experimental sciences. Each school must submit for moderation five marked sets of candidates' work in each subject, selected to represent the full range of quality of work submitted by students in that subject. If the moderators' remarking of the students' work samples indicates a disparity in standards, a statistical adjustment is made to all the internal assessment marks of the teacher involved, and a moderator who is an experienced IB teacher remarks the work. In mathematics, for example, each moderator reviews about 50 portfolios. Each then sends a sample of five sets of student work to a senior moderator, who repeats the grading and sends samples of that work to a principal moderator in each subject. The senior moderator also sends a report to the IBO for inclusion in the chief examiner's report.

How Examination Results Are Reported

IBCA communicates examination results directly to the secondary schools. The schools, in turn, are responsible for ensuring that the results are communicated to candidates. IBNA communicates the results to colleges and universities. The results include scores on each examination taken, as well as marks for the Theory of Knowledge course and the Extended Essay and cumulative scores for diploma candidates. A profile of candidates' grades is available to schools for each examination session. The profile is only for candidates whose examinations are entered by that school and includes predicted grades; examination grades, including marks for each paper; and

¹⁴George Pook, assessment director, IBCA (personal communication, May 31, 2001).

internal assessment grades, indicating any adjustments made. All sections of the examination papers are made available to teachers for use in their classrooms 24 hours after the testing date.

The IBO publishes yearly detailed reports for each subject that include mark bands for each score, general comments on the application of mark schemes to free-response problems, and comments on the strengths and weaknesses of the candidates in the treatment of individual questions. The subject reports also describe areas of the program and examination that appeared to be difficult for candidates, as well as areas in which candidates appeared to be especially well prepared. Recommendations are offered for teachers regarding assistance and guidance that should be provided for future candidates. Examples from the May 2000 chemistry subject report include the following: “Overall, it appeared that the weaker candidates . . . did not fully understand the concept of intermolecular forces and typically described covalent bond strengths as affecting boiling points. This is something that teachers might place greater emphasis on in class” (IBO, 2000c, p. 5).

The subject report also includes a detailed discussion of the internal assessment and recommendations directed at improving the laboratory program. For example, the May 2000 report states: “Overall most schools presented a suitable Practical Scheme of Work, although some schools presented programs that were significantly deficient, either in the total experimental hours completed or in the degree of syllabus coverage The depth and breadth of the experiments was generally found to be good. New teachers are clearly considering the depth of the syllabus when designing experiments, at times with limited resources. These efforts are recognized and applauded” (IBO, 2000c, pp. 17–18). The biggest problem continues to be in providing students with opportunities to demonstrate the internal assessment planning (a) and planning (b) criteria: “These skills cannot be properly assessed if teachers provide students with the purpose, hypothesis and/or procedures for experiments. Some teachers consistently gave far too much direction in their instructions (purpose, method, data table, sample calculations etc.). Candidates have been deprived of the opportunity to design realistic methods for the control of variables. Teachers must use open-ended questions in order to facilitate the assessment of Planning (a) and Planning (b)” (IBO, 1999a, p. 414).

Yearly detailed narrative reports are made available to individual schools, for a fee, on the performance of their students as a group for each subject examined. The reports include comments on students’ general examination techniques, along with suggestions for improvement, comments on overall performance in each section of the examination, analysis and evaluation of candidates’ performance on individual questions, and recommendations and guidance for future candidates. Examiners write these reports at the time of

marking and then add statistical data and a description of the mark schemes (IBO, 2000d, p. B1). The reports are substantial (7–10 pages) and include the following detailed information:

- Comments on the candidates' approach to answering the questions on each test paper, with suggestions for improvement.
- Quantitative information on the numbers of candidates answering particular questions.
- Comments on the overall performance of candidates in relation to all portions of each examination paper.
- An analysis and evaluation of candidates' performance on individual questions in relation to the marking scheme.
- Recommendations and guidance for future candidates.

Each school can also receive a *Moderation Report on the Internal Assessment* that provides information on the differences between the teachers' marks for their students and the marking by the moderator for the internally assessed samples of work. This information lets teachers know whether they are applying the standards correctly (i.e., the average mark awarded by the teacher is within 10 percent of the average mark awarded by the moderator) and consistently (i.e., the correlation between teacher and moderator marks is 0.85 or greater). Also provided are written comments from the moderators on feedback forms for each subject (International Baccalaureate Form 4/IAF, Internal Assessment Feedback Form: Group 4). These comments are provided in the form of responses to questions about clerical/procedural details, as well as the students' experimental work, including the following:

- Were the investigations/projects appropriate for the assessment of particular criteria?
- Was the practical program of the correct duration?
- Was the syllabus coverage (core, additional high level, and options) appropriate?
- Was the practical scheme of work of appropriate complexity?

IB PROFESSIONAL DEVELOPMENT

What Is Known About the Preparation and Credentials of IB Teachers

Because the credentials of prospective IB teachers are submitted as part of a school's application for membership in the IBO, initial staffing decisions and teaching assignments for IB courses are made as part of a comprehensive school plan. IB teaching assignments may be given to experienced or

novice teachers. The IBO has established neither teacher qualifications nor standards for faculties, although the application process does ensure that, at least initially, prospective IB teachers attend an IB workshop (see the next subsection). The IBO also does not certify teachers and is not involved in monitoring staffing changes after a school has become an IB school. Consequently, there is not much more information available about the qualifications of IB teachers than exists for AP teachers.

Professional Development Experiences of IB Teachers

One prerequisite for a school's obtaining permission to offer the IB program is that every teacher who will teach IB courses must attend a 3- to 5-day workshop offered by IBNA. Teachers new to an already authorized school also must attend an IB workshop, preferably before they begin to teach IB courses. In addition, the IBNA regional office is responsible for conducting weeklong professional development workshops for IB teachers and administrators during the summer, as well as 3- to 5-day workshops during the school year. IBNA has also facilitated the establishment of regional organizations for IB schools. These organizations are supported by IBNA in holding conferences and workshops several times each year. Schools and/or school districts budget resources annually to support attendance by teachers and administrators at these sessions, which are held both nationally and regionally. Experienced IB teachers typically work with representatives from IBNA to prepare materials for and plan and conduct the sessions.

Both the conferences and workshops focus on providing guidance and resources for the implementation of IB programs and development of course curricula. Workshops focus on general topics unique to IB, including the following:

- Restructuring of the school schedule and course registration to accommodate IB course requirements.
- Internal assessment.
- Restructuring of the ninth- and tenth-grade curriculum to prepare students for IB courses.
- Characteristics of IB students.
- Use of international examples and illustrations in the curriculum.

Experimental science workshops focus on designing laboratory experiences that will enable students to meet specific internal assessment criteria. The most recent focus has been on the planning criteria, as the IB examiners have found that the practical work done in most classrooms does not afford students opportunities to practice the skills needed in planning their own

experiments. In most mathematics workshops, time is spent on preparing teachers to teach an unfamiliar and expanded mathematics curriculum, including vectors and matrices; probability and statistics; and the optional topics—statistics, abstract algebra, and further geometry.

A dialogue exists between IB teachers and the IBO that is not a feature of the AP program. Every teacher completes feedback forms following each examination, answering questions about both the emphases of the examination and the content and form of individual test items. The results are summarized by IBCA and provided both to teachers and to the development committees, driving changes in curriculum and instruction the following year, as well as in the assessment instrument itself. After the examinations have been graded, each teacher receives a subject report (general comments about all of the student responses worldwide on the examination) and a school report (specific comments about their students' performance on the written examination and internal assessment, as well as comments and suggestions about the practical program in each discipline at the school). The comments provided to the schools and teachers serve as the impetus for corresponding changes in the instructional program aimed at improving students' test scores. Additionally, the IBO maintains an online curriculum site so IB teachers can receive the most current information about the curriculum.

5

Other Opportunities and Approaches to Advanced Study

Advanced Placement (AP) courses and International Baccalaureate (IB) programs are designed to meet the educational needs of high school students who are motivated and prepared for academic challenges beyond those that characterize most high school curricula. They are the only two nationally recognized, comprehensive, multisubject programs offered for this purpose in the United States. This chapter reviews other current opportunities for advanced study and some of the more common alternative models for providing college-level learning to high school students. It also describes some of the more widely recognized enrichment programs that provide opportunities for advanced study in settings other than classrooms, including internships and mentorships and academic and research competitions.¹ Many students, even those enrolled in AP, IB, or other formal programs, take advantage of some of these enrichment activities.

ALTERNATIVES FOR PROVIDING COLLEGE-LEVEL LEARNING IN HIGH SCHOOL

There are many opportunities for high school students to engage in college-level learning through local and state-sponsored programs. Some of these alternative programs follow the AP content outlines; others do not. Although many of the programs award college credit to high school students, less is documented about the transferability of credits earned by students in these alternative programs than is the case for credits earned through

¹Some students who pursue independent study document their learning and eligibility for college credit by taking one of the subject tests offered as part of the College-Level Examination Program (CLEP). Traditionally, CLEP examinations have been taken by adults who have been out of school for a long time. However, the College Board is beginning to encourage high schools to offer both AP and CLEP opportunities to their students (<http://www.collegeboard.org/clep/clephs/html/hs004.html> [November 27, 2001]).

qualifying scores on AP or IB examinations. As a result, an increasing number of students who participate in alternative college-level learning programs or in courses taught in specialized schools that do not offer AP classes document their achievement for college credit and/or placement by taking AP examinations in the appropriate subject area.² (IB does not allow students to take subject examinations unless they have completed the corresponding course at a school authorized to offer the IB program.)

The committee did not have the information or resources needed for a careful evaluation of the effectiveness of any of these alternative opportunities, but does note that such evaluation is necessary because there is tremendous variability among these programs, even those ostensibly designed for the same purpose. Further, there are no standardized external assessments, such as those used in the AP and IB programs, to measure student learning or the quality of the programs themselves. The committee suggests that systematic evaluation of these models be conducted to provide objective data about their quality and their effects on students, teachers, high schools, colleges, and universities.

Collaborative Programs

With the exception of AP, the most prevalent option for college-level learning has evolved from collaborative efforts among universities, 2- or 4-year colleges, and high schools. In some cases, the colleges, universities, or high schools involved initiate these collaborations; others are mandated by state legislatures or other policymaking entities. Although these collaborations differ in terms of funding sources, site of instruction, faculty, class composition, and the use of technology (Russell, 1998), they frequently take one of the following forms:

- College courses taught in high schools.
- Dual-enrollment options.
- Concurrent enrollment options.
- Prematriculation enrichment programs designed for specific groups of students, including talented, minority, and able but underprepared or unmotivated students.

Rationales for promoting college-level learning for high school students include (1) strengthening the high school curriculum and raising expectations for high school students; (2) decreasing the total number of credits students need to complete college, thus reducing, at least potentially, both the time required for the baccalaureate and costs to parents, students, and

²Lee Jones, College Board director of AP programs (personal communication), 2001.

taxpayers; and (3) offering the potential to enrich students' undergraduate college experiences by reducing the need to take some introductory courses and allowing earlier entry into more-advanced courses, facilitating double majors, and permitting students to enroll in a more enriched array of electives (Greenberg, 1992; Johnstone, 1993). Others point to the positive social consequences of college and high school partnerships, asserting that such partnerships provide opportunities for students who attend schools where AP, honors, and gifted-and-talented courses are not readily available (Tafel and Eberhart, 1999).

College Courses Taught in High School

College courses taught in high school are typically the product of cooperative educational program agreements between high schools and colleges to offer college courses for credit in the high school. The postsecondary institutions are usually responsible for the curricular content and for standards, administrative support, and program monitoring. High school faculty, supervised by college faculty, frequently teach these courses.³

Both college and high school administrators and faculty have been raising concerns about the widespread implementation of these types of programs. Their concerns revolve around the following:

- Qualifications of the teachers who teach the courses.
- Policies for awarding college credit.
- Characteristics of a "qualified" student.
- Impact on the high schools' curricula.
- Difficulties associated with maintaining an atmosphere in high schools that is commensurate with the instructional/social setting and expectations of a college class.
 - Impact on the workload of high school teachers selected to teach university-level courses.
 - Instructional models that stress teacher-dominated class discussions to cover the scope of a college course.
 - Costs.

Dual Enrollment

Dual-enrollment options usually involve high school students taking college courses that allow them to earn both college credit and credit to-

³Syracuse University's Project Advance is one of the oldest and most widely recognized programs of this type. Information about this program can be accessed at <http://supa.syr.edu/> (November 27, 2001).

ward a high school diploma so that high school graduation is not delayed. These programs enable students to attend nearby colleges, sometimes at reduced tuition rates. State departments of education and/or local school boards certify the majority of dual-enrollment programs. In most cases, students attend the college as full-time students and use the college credits obtained to meet high school graduation requirements. At least 38 states have formal dual-enrollment agreements between public high schools and community colleges (Reisberg, 1998), and according to data gathered by the State Higher Education Executive Officers (Russell, 1998), the phenomenon shows no signs of abating. Tech Prep,⁴ 2+2,⁵ and middle-college high school⁶ programs are usually built around dual-enrollment agreements. Yet a recent report published by the Association of American Colleges and Universities (Johnstone and Del Genio, 2001) finds fault with a number of these dual-enrollment arrangements, including those between 2-year colleges and high schools.

Concurrent Enrollment

Concurrent-enrollment programs allow high school students to take courses at local colleges or universities for credit while still in high school. One key difference between college courses taught in high school and concurrent enrollment is that students in the latter programs enroll in courses either taught by college faculty at the college's campus or delivered to the high school site by the college, whether through visits by faculty or electronically. In some cases, school districts cover a portion of the tuition costs, especially if they are unable to meet the educational needs of particular

⁴Tech Prep is a nationwide career development system that provides a high school student with a planned program of study that incorporates academic and career-related courses articulated between the secondary and postsecondary levels. The program leads to a diploma, degree, or 2-year apprenticeship certificate. All partners (secondary, postsecondary, and private sector) develop a Tech Prep program cooperatively. The program may also articulate from a community college to a 4-year baccalaureate degree. The program most typically provides technical preparation in a career field such as engineering; technology; applied science; a mechanical, industrial, or practical art or trade; agriculture; health occupations; business; or applied economics.

⁵2+2 programs allow students to complete 2 years of a vocational program in high school and the second 2 years at a community college.

⁶Students at middle-college high schools usually take high school and college courses on a community college campus. The programs began as a means to serve capable but unsuccessful students. Their purpose is to serve as a transition between high school and college for at-risk youth.

students. Students who participate in concurrent-enrollment programs typically earn college credit for their coursework,⁷ but may or may not earn high school graduation credit. The decision to award high school graduation credit is almost always made by the local school district.

Frequently, students who take advantage of this type of arrangement have exceeded the offerings of their home high school in a particular discipline or want to take a course in a discipline not offered at the high school. Concurrent-enrollment opportunities are quite common in mathematics, particularly in geographic areas where there may not be enough students to offer courses such as AP calculus or those beyond AP calculus, such as Multivariate Calculus, Linear Algebra, or Differential Equations. In these cases, students may be allowed to enroll in a nearby college mathematics course with the district covering the college tuition or, in some cases, with the college offering reduced or free tuition as a community service. Students who participate in concurrent-enrollment programs usually attend high school full time and college part time.

Concurrent-enrollment options are quite prevalent in colleges. According to a 1997 State Higher Education Executive Officers' survey,⁸ approximately 90 percent of postsecondary institutions admit qualified high school students to college courses prior to graduation through concurrent-enrollment agreements. As of 1997, 204,790 students had participated in dual-enrollment, college-in-high-school, or concurrent-enrollment programs during the previous school year. In addition, many colleges and universities offer programs that enable academically advanced and highly motivated students to pursue college-level course work on a part-time basis through early morning, late afternoon, and summer classes. They do so in the belief that concurrent-enrollment programs permit students to supplement high school work with more advanced material, to pursue interests, or to build on special talents. Some colleges also report that they gain from concurrent-enrollment programs an opportunity to recruit highly able students to their campuses for full-time study after graduation from high school.

The proliferation of dual-enrollment and concurrent-enrollment programs has sparked debate among professors about whether students are unwisely

⁷Colleges routinely accept the credits they have awarded to high school students in their concurrent-enrollment programs. However, transferability to other institutions is generally at the discretion of the receiving institution. In many cases, concurrent-enrollment credits are not deemed transferable if students also use such credits to meet high school graduation requirements.

⁸A complete version of the data gathered in the survey, including detailed summaries of the status of college-level learning policies and programming within all 50 states, is available through University Microfilms International, Publication No. 9833590, Volume/Issue 59-05A, 300 North Zeeb Rd., P.O. Box 1346, Ann Arbor, MI 48106-1346.

skipping entry-level classes at the colleges they ultimately attend and ending up in advanced courses for which they are under- or unprepared. A primary concern cited is the lack of standardized plans of instruction for the courses offered in these programs. Also noted is the lack of any general measure of the quality the curriculum or the instruction that could be used in determining whether to award credit or advanced standing to students who earn credit in such programs (Reisberg, 1998).

College-Sponsored Enrichment Programs

College-sponsored enrichment programs are designed to serve specific populations of students, including talented, minority, and underprepared or unmotivated students. Most postsecondary institutions in the United States offer such programs. The configuration of the programs varies among institutions, but they usually take the form of precollege summer programs or year-long programs and activities that provide enrichment and motivation for students who are underrepresented (e.g., women and minorities in science and engineering)⁹ or those who are not fully served through conventional programs (e.g., gifted and talented students).¹⁰

Precollege summer programs offer students the opportunity to earn college credit in residential summer school programs while living on college campuses. Students usually attend these programs during the summer following the tenth or eleventh grade. Participants typically take regular college courses along with undergraduates from the host institution and other colleges. These programs are usually designed to provide academic enrichment, foster independence, and promote good work habits.

Specialized Schools

Another vehicle for providing advanced study to secondary students is a specialized school. Most states and many school districts have developed specialized schools that bring together academically talented students and offer them an educational experience geared to their high abilities and their need for peers who share their interests. Specialized schools have proliferated across the country in response to research demonstrating that high-

⁹For example, the Summer High School Apprenticeship Research Program (SHARP) Program is a national enrichment and support effort aimed at increasing the numbers of qualified minority students in sciences and engineering by offering internships and mentorships to qualified students. (See the discussion of internships and mentorships later in this chapter.)

¹⁰The Center for Talented Youth at The John Hopkins University is an example of a program designed to provide academic enrichment to highly gifted students through flexibly paced courses.

ability students develop greater expectations, feel better about themselves, and engage in higher-level processing or discourse when working with other students of similar abilities (Fuchs, Fuchs, Hamlett, and Karns, 1998).

Programs designed to meet the needs of these high-ability learners include governors' schools, both academic year and summer programs; residential and day academies that specialize in mathematics, science, and technology; charter schools;¹¹ schools-within-a school;¹² and magnet schools.¹³ Admission to most of these programs is highly competitive and selective. The configuration of these specialized schools varies markedly from institution to institution. Some of the programs embrace innovative curricula and instructional approaches; others incorporate and/or expand on programs such as AP or IB; while still others use some of the college-level learning options described above.

There are 58 secondary schools that belong to The National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology.¹⁴ In addition, there are hundreds of other specialized schools, some of which focus on mathematics and science, which are not members of that organization.

Distance Learning

Technology has created myriad opportunities to provide advanced study options for students who otherwise might not have access to such programs. As with the other opportunities described in this section, distance learning is a rapidly growing national phenomenon that is configured in a variety of ways, depending on a program's mission and available technology.

¹¹A publicly funded school that is formed by legislation rather than by the standard school incorporation process. It has the autonomy to make decisions concerning structure, curriculum, and educational emphasis and is held accountable for the academic achievement of its students by means of its charter (www.uscharterschools.org [November 23, 2001]).

¹²A separate and autonomous unit formally authorized by the board of education and/or superintendent that plans and runs its own program, has its own staff and students, and receives its own separate budget. The school-within-a-school usually reports to a district official instead of being responsible to the building principal except in matters of safety; teachers and students typically are affiliated with the school-within-a-school as a matter of choice (Raywid, 1995).

¹³A school or education center that offers a special curriculum capable of attracting substantial numbers of students of different racial backgrounds. A key feature of magnet schools is a specialty curriculum designed to embrace a subject matter or teaching methodology not generally offered to students of the same age or grade level under the same local education agency, such as a science–technology center or a center for the performing arts (Magnet School Assistance Program, Title V, Part A of the Elementary and Secondary Education Act, as amended in 1994).

¹⁴More information can be found at: <http://www.ncsssmst.org/> (November 27, 2001).

For many years, distance learning was used to meet the needs of home schoolers, students seeking independent study options for acceleration or graduation, and those in rural areas who did not have access to enriched educational options. The movement has grown exponentially during the past decade. State departments of education, commercial enterprises, colleges and universities, and high schools are the most frequent sponsors of distance-learning opportunities.

Televised courses were one of the first strategies used for distance learning. For many years, courses were broadcast on network television for adult learners who did not have access to schools. In the past decade, state departments of education have been tapping this resource to provide courses not otherwise available to high school students, particularly in small and rural schools. Although attempts have been made to make televised courses more interactive, they still rely almost exclusively on a lecture format. Teachers conduct classes from electronic classrooms, and students participate by watching the classes at home or at school. Computers, telephones, and fax machines allow students to communicate with the instructor and to ask questions for clarification, but responses are not always immediate. New technology is poised to change this situation. High-speed data networks and online discussions have made communication with telecourse faculty during live broadcasts easier to manage, and the combined use of computers, video cameras, and microphones has created opportunities for live, interactive dialogue between students and faculty that can be heard by other students in different locations. Nonetheless, little is known about the quality of learning that can be supported by televised courses, and the committee notes that further research on this strategy is necessary.

In discussing the viability of using televised courses for the advanced study of science, the committee noted several additional problems. These include providing laboratory experiences primarily by demonstration.¹⁵ The committee believes research is needed to evaluate the effectiveness of this practice in supporting learning with understanding and that alternatives should be investigated if necessary. Another concern is the inability of telefaculty to gain a clear understanding of students' conceptions and misconceptions and to adjust teaching to reflect students' initial understandings. Additionally, there is little opportunity in the context of a televised lecture to encourage the development of students' metacognitive skills.

¹⁵Alternatives to demonstration include the use of regional centers for laboratory work and agreements with high schools and colleges to offer the laboratory component. In these cases, students must report to a central location at specified times. Other alternatives include the use of micro laboratories that can be conducted by students in their homes.

Web-Based Courses

Web-based courses are offered over the Internet. Internet-based distance learning makes it possible for commercial enterprises, as well as nonprofits such as universities, to deliver courses to students on a for-profit basis. Some of these offerings are single courses;¹⁶ others are part of a system, such as a virtual high school or university. A compelling feature of online courses, according to many observers, is their flexibility and accessibility. Students can download a lecture when it is convenient to do so and can have access to data, demonstrations, and immediate feedback when they need them. In some cases, interactive features are used; for example, students can be given an assessment and its results used to tailor instruction for them.

The committee found that the number of Web-based courses is increasing rapidly but that there is little empirical data to support their creators' claims of effectiveness in achieving the stated learning objectives. In fact, issues noted above with regard to televised courses also exist for many Web-based courses. In addition, students enrolled in Web-based courses often work alone, without other students or a teacher present (see Chapter 6, this volume, for a discussion of the social nature of learning).¹⁷ More research is needed to evaluate the quality of learning that is supported by Web-based courses and the ways in which technology can be used to support learning with understanding. Indeed, there has recently been some concern expressed that AP courses taught via the Internet are not adequately preparing students for the examination (Carr, 2001; Kuehn, 2001¹⁸). The College Board is interested in taking a more active role in monitoring Web-based AP courses to ensure that program standards are being met (CFAPP, 2001).

Many of the committee's concerns related to the effectiveness of Web-based courses used for advanced study in mathematics and science are echoed in a report recently released by the Web-Based Education Commission.¹⁹ This report acknowledges that the Internet has great potential to

¹⁶APEX Learning Systems and Class.com are examples of Web-based programs offered by for-profit organizations. The effectiveness of these programs in achieving their goals has recently been questioned by parents, students, and teachers, who have found the learning outcomes to fall short of what was promised by the program developers (Carr, 5/25/2001).

¹⁷Televised courses offered in high schools frequently have a teacher's assistant in the classroom with students as they are viewing the course on television.

¹⁸Available at <http://www.californiastar.com/courses.html> (January 15, 2001).

¹⁹The Web-based Education Commission was established by the Higher Education Act Amendments of 1998. Its 16 members were appointed by President Clinton, Education Secretary Richard Riley, and the Democratic and Republican leadership of Congress. The full report is available at <http://www.ed.gov/offices/AC/WBEC/FinalReport/> (November 23, 2001).

address many challenges facing schools and students, but emphasizes that content available for learning on the Web currently is variable in quality: some is excellent, but much is mediocre. To date, a great deal of emphasis has been placed on developing the technology, but “. . . dazzling technology has no value unless it supports content that meets the needs of learners” (Education Commission to the President of the United States, 2000, p. 12).

Virtual high schools are a rapidly increasing phenomenon (Carr, 2000). Many evolve from virtual universities and are sponsored by a postsecondary institution. Illinois, Maryland, Michigan, New Mexico, Utah, and West Virginia have all started or are planning to start statewide virtual high schools. States that have previously had such programs in place include California, Florida, Indiana, Kentucky, Massachusetts, and Nebraska. While all of the state virtual high schools are organized and financed slightly differently, many appear to adhere to a model in which the virtual high school is a division of the virtual university and shares the same infrastructure.

Nearly all university-sponsored virtual high schools started with AP-level courses, but they now are drawing on a variety of different sources to supply the online courses offered. Several plan to purchase courses from APEX Online Learning, which focuses on creating and delivering online AP courses; others are developing their own courses by contracting with teachers or schools for the use of courses created by virtual high schools in other states (Carr, 2000).

A model for a virtual high school that is not affiliated with a single college or university is the Virtual High School Project, a collaboration among high schools from around the country. In exchange for contributing a small amount of teaching time, a participating school can offer its students NetCourses ranging from advanced academic to technical and specialized courses. Schools donate computers, Internet connectivity, and staff time. Each school also provides a site coordinator who is responsible for project management and support of teachers and students at the local school. Teachers must successfully complete The Teachers Learning Conference, a graduate-level NetCourse designed to expose participants to educational strategies and technologies for NetCourse teaching.

Computer-Based Multimedia Courses

Computer-based multimedia courses combine online technology with CD-ROM, video conferencing, electronic communication, Web-based laboratory, and other technologies. These courses allow for self-paced instruction that is tailored to the individual’s needs; students can spend as little or as much time as necessary to master a concept. Some include contact with live tutors.

The Education Program for Gifted Youth (EPGY) at Stanford University sponsors a computer-based, multimodal delivery system that exemplifies this approach. The courses use a combination of CD-ROM and Internet technologies to provide students with a multifaceted, highly individualized learning environment. The courses are organized around lectures that are computer-based and multimedia, consisting of voice accompanied by synchronized graphics. The program is designed to allow flexible pacing of instruction. Students who demonstrate ready mastery move quickly through a course, while slower learners receive additional instruction. Formative evaluation of student progress through ongoing data collection and analysis is a key component of the program and is used to adjust instruction for individual students. In all courses, lectures are followed by exercises in which students answer questions that are evaluated by the computer. Additional computer-based instruction and practice are provided to students whose responses to these questions indicate that they need further assistance. In addition, human instructors provide support to these and other students by telephone and electronic mail, as well as through a virtual classroom. To participate in a virtual classroom, students connect via the Internet, using voice and shared whiteboard conferencing software to create a real-time interactive lecture environment.

The committee did not have the opportunity to fully evaluate the Stanford program, but notes that it appears to be a promising model worthy of further evaluation. In evaluating this or other computer-based programs, the focus should be on how well the curricula, instruction, and companion assessment techniques align with the principles of learning with understanding detailed in Chapter 6 of this volume. Student achievement—the ultimate indicator of program effectiveness—should be measured by assessing not only students' command of factual knowledge, but also their conceptual understanding of the subject matter and their ability to apply that knowledge to learning new concepts.

ENRICHMENT ACTIVITIES

Even in schools with strong curricular and instructional resources, educators seek to create activities that will enhance and enrich student learning. With the exception of some national academic and research competitions, most of these activities are the product of collaborations involving individual localities; postsecondary institutions; professional organizations; or research entities, such as the National Aeronautics and Space Administration (NASA) or the National Institutes of Health (NIH). Enrichment activities are typically targeted at high-ability learners, students with strong interests or talent in a

particular discipline, and members of groups who are underrepresented in particular occupations.

Internships and Mentorships

Eminent individuals tend to have been profoundly influenced by a single or several mentors or role models (Goertzel, Goertzel, and Goertzel, 1978; Kaufmann, Harrel, Milam, Woolverton, and Miller, 1986; Torrance, 1984). Internships and mentorships can provide students with such experiences.

Internship programs expose students to research and career development opportunities through placement in research facilities or industries. These placements can be during the summer, part time during the school year, or longer term. Research facilities, large government agencies, local colleges, and university scientists all sponsor internships. NIH and NASA both offer research opportunities to high school students. Individual teachers frequently arrange for their students to participate in internships and research activities in local laboratories or universities. The committee learned of many teachers who have marshaled the resources of their communities to provide meaningful experiences for science and mathematics students. We recognize the extraordinary amount of time and energy required to arrange these types of activities and commend the efforts of these individuals.

There are also numerous summer enrichment opportunities that enable students to participate in specialized and challenging programs of advanced study. Some of these programs are designed to address the needs of high-ability learners seeking opportunities to work on problems that are not strictly defined so they can help structure their own learning experiences. An example of this type of program is the nationally recognized Arnold Ross program for advanced mathematics students, held annually at Ohio State University.²⁰ Another nationally recognized initiative is the Program in Mathematics for Young Scientists at Boston University.²¹ Others, such as the University of California's Early Outreach Program, focus on compensatory and motivational activities that encourage and support students in efforts to be successful in more advanced curricula.²² Many U.S. colleges and universities sponsor this type of program.

²⁰Additional information about this program is available at <http://www.math.ohio-state.edu/ross/> (November 23, 2001).

²¹Additional information about this program is available at <http://math.bu.edu/INDIVIDUAL/promys/indice.html> (November 23, 2001).

²²See <http://uga.berkeley.edu/apa/APA%20Home/eaop/default.htm> (November 23, 2001).

Academic and Research Competitions

Many students participate in activities that require them to develop expertise through self-directed research or intense study of a topical area and then demonstrate their learning by participating in a competition. Some academic and research competitions are geared toward participation by teams of students; others are designed for individual participants. The goal of most academic competitions is to provide a competitive outlet for students who are particularly talented or interested in an area or subject by encouraging them to engage in problem-solving activities that are complex and challenging. Examples of these types of programs include science fairs, mathematics and science Olympiads, the Intel and Duracell/National Science Teachers Association science competitions, inventors' competitions, and bridge-building competitions. External judging is usually a component of these programs. Coaching and mentorship are important aspects of the preparation students receive.

Critics of such competitions cite disparities in the resources available to students and the negative aspects of encouraging competitiveness instead of the cooperation that is more in keeping with the way modern science is conducted in the field. Some worry about the lack of participation by students who have the ability to undertake such work but have not had opportunities in their schools to demonstrate this ability. Thus, these critics say, the competitions reward those who already have access to greater resources and opportunities. Proponents cite the unique opportunity these activities provide for students to engage in problem-solving activities not typically available through classroom curricula.

Alternative Curricular and Instructional Approaches

Students and schools differ in many ways that are important to teaching and learning. Consequently, no single course structure or approach, including those as widely used as AP and IB, can meet the educational needs of every high school student who is ready for advanced study. For example, not all schools have adequate resources (physical, financial, or human) to teach high-quality AP courses, and implementing IB requires a level of schoolwide commitment that not all schools are prepared or able to undertake. Additionally, the goals and objectives of individual schools vary in accordance with their local communities' educational values and beliefs. State educational standards that describe what students who are educated in the state should know and be able to do at particular grade levels play an important role in determining what is taught and the way instruction and curriculum are organized. This variation underscores the need for alternatives to the AP and IB programs.

The committee suggests, however, that before adopting any curriculum for advanced study, those responsible for selecting programs do two things. The first is to evaluate the programs under consideration for alignment with the principles of learning outlined in this and other reports, such as *How People Learn: Brain, Mind, Experience, and School (Expanded Edition)* (National Research Council, 2000b). In so doing, it is important to ensure that the program not only moves students along the learning continuum by increasing their content knowledge, but also fosters a deep conceptual understanding of the subject matter. Second is to assess whether the school has the necessary infrastructure and resources to implement the program successfully, including qualified teachers and adequate time and money to provide ongoing, high-quality professional development opportunities for members of the staff who will be responsible for implementing the program (see Chapter 7, this volume).

CONCLUSION

The two extant national models for advanced study (AP and IB) cannot meet the educational needs of all students. The committee learned of many advanced study alternatives that have been developed by individual schools and school districts, sometimes in conjunction with universities. While the committee applauds local efforts to develop original advanced study programs, we believe such programs are not enough, and additional national programs are needed. This call for more national programs stems from research identifying the benefits that accrue when students and teachers are part of national educational efforts.

In calling for more national programs, the committee wishes to be quite clear that we are not asking for more programs that merely replicate those that already exist. Rather, the committee urges universities, policymakers, and curriculum specialists to encourage the development, evaluation, and dissemination of information about promising alternatives that can help increase access to advanced study for students from diverse backgrounds and communities, as well as those whose learning styles or interests are not adequately addressed by existing national programs.

6

Learning with Understanding: Seven Principles

During the last four decades, scientists have engaged in research that has increased our understanding of human cognition, providing greater insight into how knowledge is organized, how experience shapes understanding, how people monitor their own understanding, how learners differ from one another, and how people acquire expertise. From this emerging body of research, scientists and others have been able to synthesize a number of underlying principles of human learning. This growing understanding of how people learn has the potential to influence significantly the nature of education and its outcomes.

The committee's appraisal of advanced study is organized around this research on how people learn (see, for example, Greeno, Collins, and Resnick, 1996; National Research Council [NRC], 2000b; 2001a; Shepard, 2000). Our appraisal also takes into account a growing understanding of how people develop expertise in a subject area (see, for example, Chi, Feltovich, and Glaser, 1981; NRC, 2000b). Understanding the nature of expertise can shed light on what successful learning might look like and help guide the development of curricula, pedagogy, and assessments that can move students toward more expert-like practices and understandings in a subject area. To make real differences in students' skill, it is necessary both to understand the nature of expert practice and to devise methods that are appropriate to learning that practice.

The design of educational programs is always guided by beliefs about how students learn in an academic discipline. Whether explicit or implicit, these ideas affect what students in a program will be taught, how they will be taught, and how their learning will be assessed. Thus, educational program designers who believe students learn best through memorization and repeated practice will design their programs differently from those who hold that students learn best through active inquiry and investigation.

The model for advanced study proposed by the committee is supported by research on human learning and is organized around the goal of fostering

learning with deep conceptual understanding or, more simply, *learning with understanding*. Learning with understanding is strongly advocated by leading mathematics and science educators and researchers for all students, and also is reflected in the national goals and standards for mathematics and science curricula and teaching (American Association for Advancement of Science [AAAS], 1989, 1993; National Council of Teachers of Mathematics [NCTM], 1989, 1991, 2000; NRC, 1996). The committee sees as the goal for advanced study in mathematics and science an even deeper level of conceptual understanding and integration than would typically be expected in introductory courses.

Guidance on how to achieve learning with understanding is grounded in seven research-based principles of human learning that are presented below (see Box 6-1).¹ In Chapter 7, these principles are used as the framework for the design of curricula, instruction, and assessments for advanced study—three facets of classroom activity that, when skillfully orchestrated by the teacher, jointly promote learning with understanding. These principles also serve as the foundation for the design of professional development, for it, too, is a form of advanced learning.

The design principles for curriculum, instruction, assessment, and professional development provide one of the organizing frameworks of the committee's analysis of the AP and IB programs (see Chapters 8 and 9, this volume). While it could be argued that all components of the educational system (e.g., preservice training and leadership) should be included (and we believe they should), our analysis was limited to these four facets. Although this framework was developed to assess current programs of advanced study, it also can serve as a guide or framework for those involved in developing, implementing, or evaluating new educational programs.

SEVEN PRINCIPLES OF HUMAN LEARNING

Principle 1: Principled Conceptual Knowledge

Learning with understanding is facilitated when new and existing knowledge is structured around the major concepts and principles of the discipline.

Highly proficient performance in any subject domain requires knowledge that is both accessible and usable. A rich body of content knowledge about a subject area is a necessary component of the ability to think and

¹The research on which these principles are based has been summarized in *How People Learn: Mind, Brain, Experience and School* (Expanded Edition) (NRC, 2000b).

BOX 6-1 Seven Principles of Learning

1. Learning with understanding is facilitated when new and existing knowledge is structured around the major concepts and principles of the discipline.
2. Learners use what they already know to construct new understandings.
3. Learning is facilitated through the use of metacognitive strategies that identify, monitor, and regulate cognitive processes.
4. Learners have different strategies, approaches, patterns of abilities, and learning styles that are a function of the interaction between their heredity and their prior experiences.
5. Learners' motivation to learn and sense of self affects what is learned, how much is learned, and how much effort will be put into the learning process.
6. The practices and activities in which people engage while learning shape what is learned.
7. Learning is enhanced through socially supported interactions.

solve problems in that domain, but knowing many disconnected facts is not enough. Research clearly demonstrates that experts' content knowledge is structured around the major organizing principles and core concepts of the domain, the "big ideas" (e.g., Newton's second law of motion in physics, the concept of evolution in biology, and the concept of limit in mathematics) (see, for example, Chi et al., 1981; Kozma and Russell, 1997). These big ideas lend coherence to experts' vast knowledge base; help them discern the deep structure of problems; and, on that basis, recognize similarities with previously encountered problems. Research also shows that experts' strategies for thinking and solving problems are closely linked to rich, well-organized bodies of knowledge about subject matter. Their knowledge is connected and organized, and it is "conditionalized" to specify the context in which it is applicable.

If one conceives of advanced study as moving students along a continuum toward greater expertise, then advanced study should have as its goal fostering students' abilities to recognize and structure their growing body of content knowledge according to the most important principles of the discipline. Therefore, curriculum and instruction in advanced study should be designed to develop in learners the ability to see past the surface features of any problem to the deeper, more fundamental principles of the discipline.

Curricula that emphasize breadth of coverage and simple recall of facts may hinder students' abilities to organize knowledge effectively because they do not learn anything in depth, and thus are not able to structure what they are learning around the major organizing principles and core concepts of the discipline. Even students who prefer to seek understanding are often forced into rote learning by the quantity of information they are asked to absorb.

Principle 2: Prior Knowledge

Learners use what they already know to construct new understandings.

When students come to advanced study, they already possess knowledge, skills, beliefs, concepts, conceptions, and misconceptions that can significantly influence how they think about the world, approach new learning, and go about solving unfamiliar problems (Wandersee, Mintzes, and Novak, 1994). People construct meaning for a new idea or process by relating it to ideas or processes they already understand. This prior knowledge can produce mistakes, but it can also produce correct insights. Some of this knowledge base is discipline specific, while some may be related to but not explicitly within a discipline. Research on cognition has shown that successful learning involves linking new knowledge to what is already known. These links can take different forms, such as adding to, modifying, or reorganizing knowledge or skills. How these links are made may vary in different subject areas and among students with varying talents, interests, and abilities (Paris and Ayers, 1994). Learning with understanding, however, involves more than appending new concepts and processes to existing knowledge; it also involves conceptual change and the creation of rich, integrated knowledge structures.

If students' existing knowledge is not engaged, the understandings they develop through instruction can be very different from what their teacher may have intended; learners are more likely to construct interpretations that agree with their own prior knowledge even when those interpretations are in conflict with the teacher's viewpoint. Thus, lecturing to students is often an ineffective tool for producing conceptual change. For example, Vosniadou and Brewer (1992) describe how learners who believed the world is flat perceived the earth as a three-dimensional pancake after being taught that the world is a sphere.

Moreover, when prior knowledge is not engaged, students are likely to fail to understand or even to separate knowledge learned in school from their beliefs and observations about the world outside the classroom. For

example, despite instruction to the contrary, students of all ages (including college graduates) often persist in their belief that seasons are caused by the earth's distance from the sun, rather than the inclination of the earth's axis relative to the plane of its orbit around the sun, which affects the amount of solar energy striking the northern and southern regions of the earth as it orbits the sun (Harvard-Smithsonian Center for Astrophysics, Science Education Department, 1987). Roth (1986) similarly found that students continued to believe plants obtain food from the soil, rather than making it in their leaves, even after they had been taught about photosynthesis; this belief persisted since many failed to recognize that the carbon dioxide extracted from the air has weight and makes up most of a plant's mass.

Effective teaching involves gauging what learners already know about a subject and finding ways to build on that knowledge. When prior knowledge contains misconceptions, there is a need to reconstruct a whole relevant framework of concepts, not simply to correct the misconception or faulty idea. Effective instruction entails detecting those misconceptions and addressing them, sometimes by challenging them directly (Caravita and Hallden, 1994; Novak, 2002).

The central role played by prior knowledge in the ability to gain new knowledge and understanding has important implications for the preparation of students in the years preceding advanced study. To be successful in advanced study in science or mathematics, students must have acquired a sufficient knowledge base that includes concepts, factual content, and relevant procedures on which to build. This in turn implies that they must have had the opportunity to learn these things. Many students, however, particularly those who attend urban and rural schools, those who are members of certain ethnic or racial groups (African American, Hispanic, and Native American), and those who are poor, are significantly less likely to have equitable access to early opportunities for building this prerequisite knowledge base (Doran, Dugan, and Weffer, 1998; see also Chapter 2, this volume). Inequitable access to adequate preparation can take several forms, including (1) lack of appropriate courses (Ekstrom, Goertz, and Rock, 1988); (2) lack of qualified teachers and high-quality instruction (Gamoran, 1992; Oakes, 1990); (3) placement in low-level classes where the curriculum focuses on less rigorous topics and low-level skills (Burgess, 1983, 1984; Nystrand and Gamoran, 1988; Oakes, 1985); (4) lack of access to resources, such as high-quality science and mathematics facilities, equipment, and textbooks (Oakes, Gamoran, and Page, 1992); and (5) lack of guidance and encouragement to prepare for advanced study (Lee and Ekstrom, 1987).

Students who lack opportunities to gain important knowledge and skills in the early grades may never get to participate in advanced classes where higher-order skills are typically taught (Burnett, 1995). Consequently, these

students may be precluded very early in their school careers from later participation in advanced study—even when they are interested and motivated to enroll. In essence, they are “tracked away.” The end result is that many students are denied access to important experiences that would prepare them to pursue the study of mathematics and sciences beyond high school.

Principle 3: Metacognition

Learning is facilitated through the use of metacognitive strategies that identify, monitor, and regulate cognitive processes.

To be effective problem solvers and learners, students need to determine what they already know and what else they need to know in any given situation. They must consider both factual knowledge—about the task, their goals, and their abilities—and strategic knowledge about how and when to use a specific procedure to solve the problem at hand (Ferrari and Sternberg, 1998). In other words, to be effective problem solvers, students must be *metacognitive*. Empirical studies show that students who are metacognitively aware perform better than those who are not (Garner and Alexander, 1989; Schoenfeld, 1987).

Metacognition is an important aspect of students’ intellectual development that enables them to benefit from instruction (Carr, Kurtz, Schneider, Turner, and Borkowski, 1989; Flavell, 1979; Garner, 1987; Novak, 1985; Van Zile-Tamsen, 1996) and helps them know what to do when things are not going as expected (Schoenfeld, 1983; Skemp, 1978, 1979). For example, research demonstrates that students with better-developed metacognitive strategies will abandon an unproductive problem-solving strategy very quickly and substitute a more productive one, whereas students with less effective metacognitive skills will continue to use the same strategy long after it has failed to produce results (Gobert and Clement, 1999). The basic metacognitive strategies include (1) connecting new information to former knowledge; (2) selecting thinking strategies deliberately; and (3) planning, monitoring, and evaluating thinking processes (Dirkes, 1985).

Experts have highly developed metacognitive skills related to their specific area of expertise. If students in a subject area are to develop problem-solving strategies consistent with the ways in which experts in the discipline approach problems, one important goal of advanced study should be to help students become more metacognitive. Fortunately, research indicates that students’ metacognitive abilities can be developed through explicit instruction and through opportunities to observe teachers or other content experts as they solve problems and consider ideas while making their thinking visible to those observing (Collins and Smith, 1982; Lester et al., 1994;

Schoenfeld, 1983, 1985). Having students construct concept maps² for a topic of study can also provide powerful metacognitive insights, especially when students work in teams of three or more (see Box 6-2 for a discussion of concept maps). It is important to note that the teaching of metacognitive skills is often best accomplished in specific content areas since the ability to monitor one's understanding is closely tied to the activities and questions that are central to domain-specific knowledge and expertise (NRC, 2000b).

Principle 4: Differences Among Learners

Learners have different strategies, approaches, patterns of abilities, and learning styles that are a function of the interaction between their heredity and their prior experiences.

Individuals are born with potential that develops through their interaction with their environment to produce their current capabilities and talents. Thus among learners of the same age, there are important differences in cognitive abilities, such as linguistic and spatial aptitudes or the ability to work with symbolic quantities representing properties of the natural world, as well as in emotional, cultural, and motivational characteristics.

Additionally, by the time students reach high school, they have acquired their own preferences regarding how they like to learn and at what pace. Thus, some students will respond favorably to one kind of instruction, whereas others will benefit more from a different approach. Educators need to be sensitive to such differences so that instruction and curricular materials will be suitably matched to students' developing abilities, knowledge base, preferences, and styles. (Annex 6-1 illustrates some of the ways in which curriculum and instruction might be modified to meet the learning needs of high-ability learners.)

Appreciation of differences among learners also has implications for the design of appropriate assessments and evaluations of student learning. Students with different learning styles need a range of opportunities to demonstrate their knowledge and skills. For example, some students work well

²Concept maps are two-dimensional, hierarchical representations of concepts and relationships between concepts that model the structure of knowledge possessed by a learner or expert. The theory of learning that underlies concept mapping recognizes that all meaningful learning builds on the learner's existing relevant knowledge and the quality of its organization. The constructivist epistemology underlying concept maps recognizes that all knowledge consists of concepts, defined as perceived regularities in events or objects or their representation, designated by a label, and propositions that are two or more concepts linked semantically to form a statement about some event or object. Free software that aids in the construction of concept maps is available at www.cmap.coginst.uwf.edu.

BOX 6-2 Use of Concept Maps

Figures 6-1 and 6-2 are examples of actual concept maps constructed by a high school student. Figure 6-1 was made at the beginning of the study of meiosis and shows that the student did not know how to organize and relate many of the relevant concepts. The student equated meiosis with sexual reproduction and was not clear on how meiosis relates to homologous chromosomes. These maps are presented without editing.

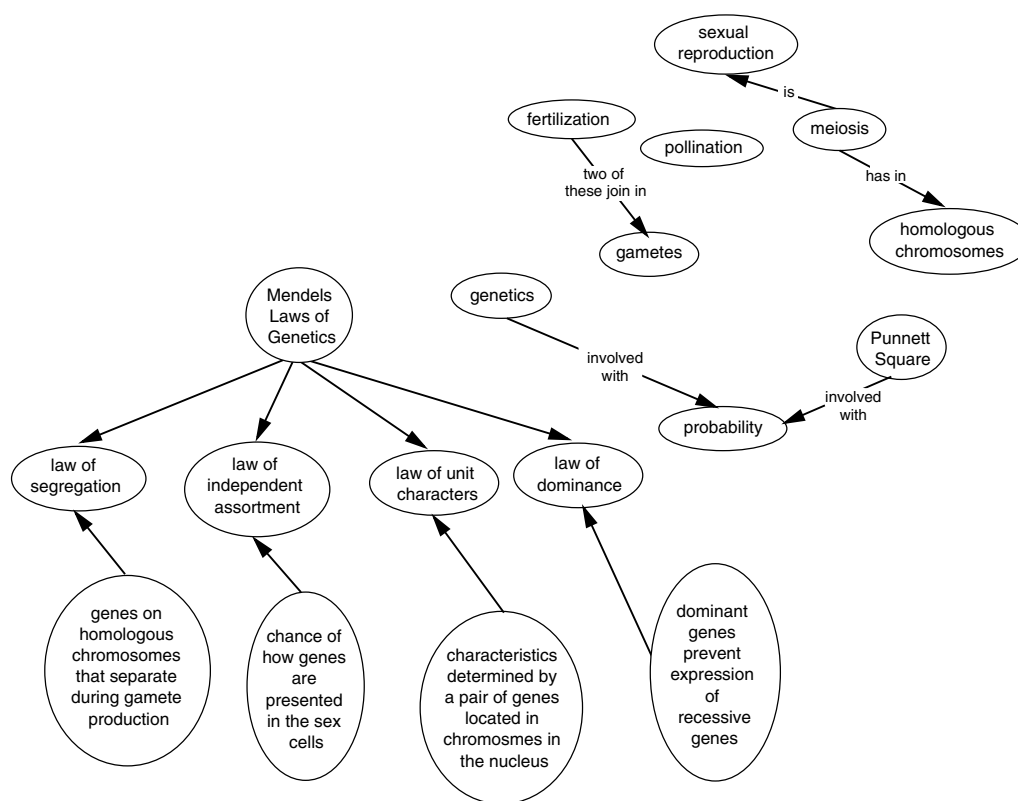


FIGURE 6-1 Concept map made by an advanced biology student early in the study of meiosis and genetics. Note that several concepts are not integrated into the student's knowledge structure, and he has the misconception that meiosis is sexual reproduction. SOURCE: J. Novak (Jan. 2001) personal correspondence. Used with permission.

Figure 6-2, a concept map made at the end of the study, reveals an elaborated, integrated understanding of the process. The student now has integrated the meanings of meiosis and sexual reproduction, homologous chromosomes, and other concepts. While some concept meanings still appear a bit fuzzy, the student has clearly made progress in the development of understanding, and his knowledge structure can serve as a good foundation for further study.

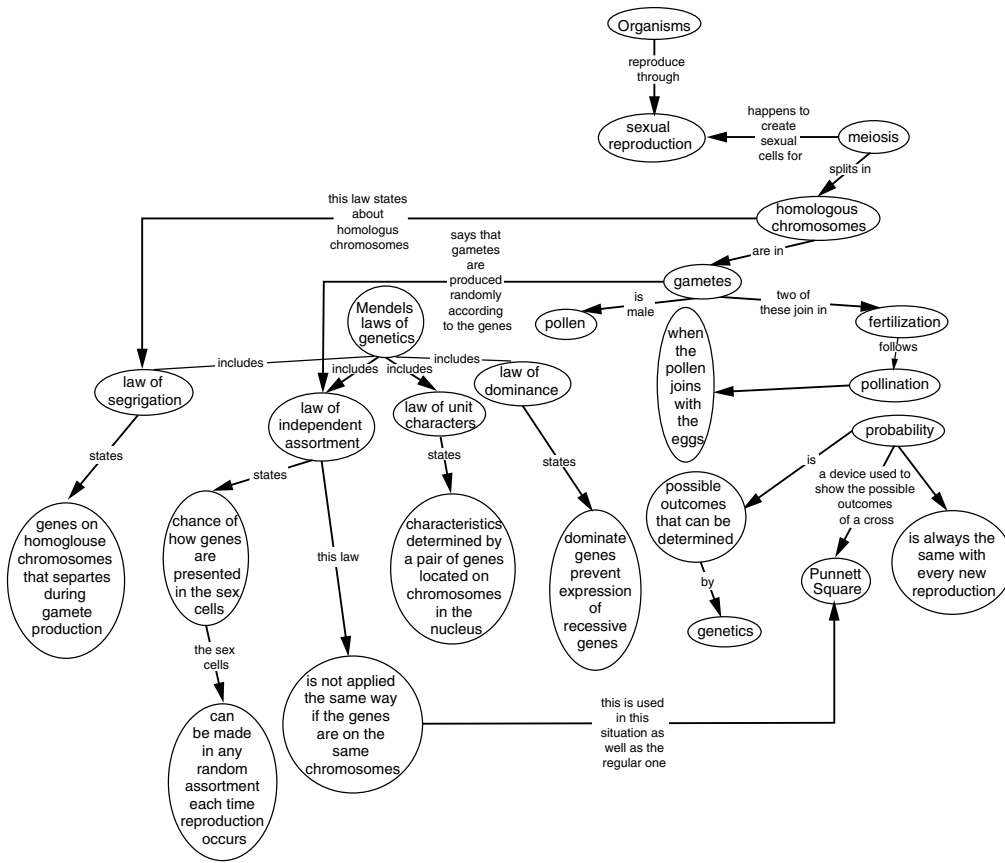


FIGURE 6-2 Concept map drawn by the same student at the end of the study unit on meiosis. Note that the original misconceptions about the nature of meiosis have been remediated, and more concepts have been integrated into the student's knowledge structure. SOURCE: J. Novak (Jan. 2001) personal correspondence. Used with permission.

under pressure, while the performance of others is significantly diminished by time constraints. Some excel at recalling information, while others are more adept at performance-based tasks. Some express themselves well in writing, while others do not. Thus using one form of assessment will work to the advantage of some students and to the disadvantage of others (Mintzes, Wandersee, and Novak, 2001; O'Neil and Brown, 1997; Shavelson, Baxter, and Pine, 1992; Sugrue, Valdes, Schlackman, and Webb, 1996).

Principle 5: Motivation

A learner's motivation to learn and sense of self affects what is learned, how much is learned, and how much effort will be put into the learning process.

Humans are motivated to learn and to develop competence (Stipek, 1998; White, 1959). Motivation can be extrinsic (performance oriented), for example to get a good grade on a test or to be accepted by a good college, or intrinsic (learning oriented), for example to satisfy curiosity or to master challenging material. Regardless of the source, learners' level of motivation strongly affects their willingness to persist in the face of difficulty. Intrinsic motivation is enhanced when learning tasks are perceived as being interesting and personally meaningful and are presented at the proper level of difficulty. A task that is too difficult can create frustration; one that is too easy can lead to boredom.

Research has revealed strong connections between learners' beliefs about their own abilities in a subject area and their success in learning about that domain (Eccles, 1987, 1994; Garcia and Pintrich, 1994; Graham and Weiner, 1996; Markus and Wurf, 1987; Marsh, 1990; Weiner, 1985). Some beliefs about learning are quite general. For example, some students believe their ability to learn a particular subject or skill is predetermined, whereas others believe their ability to learn is substantially a function of effort (Dweck, 1989). Believing that abilities are developed through effort is most beneficial to the learner, and teachers and others should cultivate that belief (Graham and Weiner, 1996; Weiner, 1985). The use of instructional strategies that encourage conceptual understanding is an effective way to increase students' interest and enhance their confidence about their abilities to learn a particular subject (Alaiyemola, Jegede, and Okebukola, 1990; Cavallo, 1996).

Cultivating the belief among a broad range of students that the ability to learn advanced science and mathematics is, for the most part, a function of effort rather than inherited talent, ability, and/or intelligence has other benefits as well. For example, the belief that successful learning in advanced study is a matter of effort fosters risk taking in course selection and promotes students' motivation to succeed in challenging situations (Novak and

Gowin, 1984). A belief in the value of effort is especially important for students who are traditionally underrepresented in advanced study. For students to maintain their beliefs about the role of effort in successful performance, teachers and other school personnel must act in ways that do not contradict students' sense that they are capable of understanding science and mathematics and that sustained effort will produce such understanding, even though there may be struggles along the way.

Several recent studies document the power of a high school culture that expects all students to spend time and effort on academic subjects and is driven by a belief that effort will pay off in high levels of academic achievement for everyone, regardless of prior academic status, family background, or future plans. When such norms and expectations are held in common for all students, they define the school's culture. In such settings, remediation of skill deficits takes on a different character, teachers are able and willing to provide rigorous academic instruction to all students, and all students respond with effort and persistence (Bryk, Lee, and Holland, 1993; Lee, 2001; Lee, Bryk, and Smith, 1993; Lee and Smith, 1999; Marks, Doane, and Secada, 1996; Rutter, 1983).

Principle 6: Situated Learning

The practices and activities in which people engage while learning to shape what is learned.

Research on the situated nature of cognition indicates that the way people learn a particular domain of knowledge and skills and the context in which they learn it become a fundamental part of what is learned (Greeno, 1993; Lave, 1991). When students learn, they learn both information and a set of practices, and the two are inextricably related. McLellan (1996, p. 9) states that situated cognition “involves adapting knowledge and thinking skills to solve unique problems . . . and is based upon the concept that knowledge is contextually situated and is fundamentally influenced by the activity, context, and culture in which it is used.” Learning, like cognition, is shaped by the conventions, tools, and artifacts of the culture and the context in which it is situated.

Because the practices in which students engage as they acquire new concepts shape what and how the students learn, transfer is made possible to the extent that knowledge and learning are grounded in multiple contexts (Brown, Collins, and Duguid, 1989). Transfer is more difficult when a concept is taught in a limited set of contexts or through a limited set of activities. When concepts are taught only in one context, students are not exposed to the varied practices associated with those concepts. As a result, students often miss seeing the concepts' applicability to solving novel problems en-

countered in real life, in other classes, or in other disciplines. It is only by encountering the same concept at work in multiple contexts that students can develop a deep understanding of the concept and how it can be used, as well as the ability to transfer what has been learned in one context to others (Anderson, Greeno, Reder, and Simon, 1997).

If the goal of education is to allow learners to apply what they learn in real situations, learning must involve applications and take place in the context of authentic activities (Brown et al., 1989). J. S. Brown and colleagues (1989, p. 34) define authentic activities as “ordinary practices of a culture”—activities that are similar to what actual practitioners do in real contexts. A. L. Brown and colleagues (1993) offer a somewhat different definition: given that the goal of education is to prepare students to be lifelong learners, activities are authentic if they foster the kinds of thinking that are important for learning in out-of-school settings, whether or not those activities mirror what practitioners do. Regardless of which definition is adopted, the importance of situating learning in authentic activities is clear. Collins (1988) notes the following four specific benefits: (1) students learn about the conditions for applying knowledge, (2) they are more likely to engage in invention and problem solving when learning in novel and diverse situations and settings, (3) they are able to see the implications of their knowledge, and (4) they are supported in structuring knowledge in ways that are appropriate for later use.

Teachers can engage learners in important practices that can be used in different situations by drawing upon real-world exercises, or exercises that foster problem-solving skills and strategies that are used in real-world situations. Such an approach provides language, activities, and procedures that can acculturate students into the community of scholars and lifelong learners. Problem-based and case-based learning are two instructional approaches that create opportunities for students to engage in practices similar to those of experts. Technology also can be used to bring real-world contexts into the classroom. The committee emphasizes that with all of these approaches, care must be taken to provide multiple opportunities for students to engage in activities in which the same concept is at work; otherwise learning could become overly contextualized.

Principle 7: Learning Communities

Learning is enhanced through socially supported interactions.

Learning can be enhanced when students have the opportunity to interact and collaborate with others on instructional tasks. In learning environments that encourage collaboration among peers, such as those in which most practicing scientists and mathematicians work, individuals build com-

munities of practice, have opportunities to test their own ideas, and learn by observing others. Research demonstrates that opportunities for students to articulate their ideas to peers and to hear and discuss others' ideas in the context of the classroom is particularly effective in bringing about conceptual change (Alexopoulou and Driver, 1996; Carpenter and Lehrer, 1999; Cobb, Wood, and Yackel, 1993; Kobayashi, 1994; Towns and Grant, 1997; Wood, Cobb, and Yackel, 1991). Social interaction also is important for the development of expertise, metacognitive skills, and formation of the learner's sense of self.

The social nature of learning has important implications for the consequences of the ways in which students are grouped for instruction. For example, students who are placed in low-track classes often have less time to collaborate and interact around instructional tasks. Research indicates that teachers in low-track science and mathematics classes spend more time than teachers in higher-track classes on routines, and more frequently provide seatwork and worksheet activities that are designed to be completed independently (Oakes, 1990). Additionally, teachers in higher-track classes often orchestrate more frequent and varied opportunities for students to participate in small-group problem-solving activities than are provided by teachers in lower-track classes, who tend to focus on behavior management and on maintaining control during learning activities. Some might contend that teachers in both types of classes are responding to the needs of their students. However, teachers must strike a balance between providing the structure that is often appropriate for low-ability students and the active engagement that allows these students to learn at deeper levels.

Newmann and Wehlage (1995) identify teaching strategies that promote intellectual quality and authenticity. One of the most powerful strategies is the "substantive conversation," in which students engage in extended conversational exchanges with the teacher and/or peers about subject matter in a way that builds an improved or shared understanding of ideas or topics. The authors stress that such subject matter conversations go far beyond reporting facts, procedures, or definitions; they focus on making distinctions, applying ideas, forming generalizations, and raising questions. According to the results of research by Gamoran and Nystrand (1990), the opportunities for such substantive engagement are far fewer in low-track than in higher-track classes.

CONCLUSION

The seven principles of learning set forth in this chapter are not ends in themselves. Their usefulness lies in the guidance they provide for the design of curriculum, instruction, assessment, and professional development for

advanced study that fosters in students a deep conceptual understanding of a domain. The next chapter articulates design principles for advanced study that draw on these principles of learning.

ANNEX 6-1

CHARACTERISTICS OF HIGH-ABILITY LEARNERS AND IMPLICATIONS FOR CURRICULUM AND INSTRUCTION

Differences among learners have implications for how curriculum and instruction should be structured.³ Provided below is an example of how a better understanding of learning can assist teachers in structuring their curricula and instruction more appropriately to meet the needs of a particular group of students. Different strategies would most likely be used to meet the needs of other students, although there might be some overlap.

Characteristic: High-ability learners display an exceptionally rich knowledge base in their specific talent domain. Within that domain, they tend to achieve formal operational thought earlier than other students and to display advanced problem-solving strategies. High-ability learners are also able to work with abstract and complex ideas in their talent domain at an earlier age.

Implication: High-ability learners are ready to access the high school mathematics and science curriculum earlier than other students. Thus the high school mathematics and science sequence should be offered to them beginning in middle school.

Characteristic: High-ability students pick up informally much of the content knowledge taught in school, and as a result, that knowledge tends to be idiosyncratic and not necessarily organized around the central concepts of the discipline.

Implication: Assessment of what the learner has already mastered through diagnostic testing is critical. Instruction needs to build on what is already known and on previous experiences, filling in the gaps and correct-

³The information in this section is drawn from research on gifted and talented learners (see, for example, Association of the Gifted and Talented, 1989; Berger, 1991; Boyce et al., 1993; Dark and Benbow, 1993; Feldhusen, Hansen, and Kennedy, 1989; Johnson and Sher, 1997; Maker, 1982; VanTassel-Baska et al., 1988; Tomlinson, 1995; VanTassel-Baska, 1998).

ing misconceptions. It also must help the student organize his or her knowledge around the central ideas of the discipline. A full course in a content area often is not needed; either it could be skipped, with gaps being filled in as needed, or the curriculum compacted. “The proper psychology of talent is one that tries to be reasonably specific in defining competencies as manifested in the world, with instruction aimed at developing the very competencies so defined” (Wallach, 1978, p. 617).

Characteristic: High-ability learners learn at a more rapid rate than other students and can engage in simultaneous rather than only linear processing of ideas in their talent domain.

Implication: The pace at which the curriculum is offered must be adjusted for these learners. The curriculum also must be at a more complex level, making interdisciplinary connections whenever possible. That is, the curriculum should allow for faster pacing of well-organized, compressed, and appropriate learning experiences that are, in the end, enriching and accelerative.

Characteristic: Many high-ability students will have mastered the content of high school mathematics and science courses before formally taking the courses, either on their own, through special programs, or through Web-based courses.

Implication: Opportunities for testing out of prerequisites should be provided. Many high-ability students could be placed directly in an AP science course, skipping the typical high school-level prerequisite, or begin the IB program earlier than is typical.

Characteristic: High-ability students often can solve problems by alternative means and not know the underlying concept being tapped by a test item (e.g., can solve an algebra problem but not know algebra).

Implication: Assessments should not be solely in multiple-choice format; students must be able to show their work in arriving at a solution.

Characteristic: The motivation of high-ability students to achieve often becomes diminished because of boredom in school, resulting in underachievement.

Implication: Because one facet of effective teaching involves assessing the student’s status in the learning process and posing problems slightly exceeding the level already mastered (Hunt, 1961), it is important to provide curricula for high-ability students that are developmentally appropriate for them. Doing so will not only meet the intellectually talented student’s educational needs, but also facilitate his or her development of good study skills, more realistic self-concepts, and achievement motivation. Growth in

achievement motivation and self-efficacy arises out of challenge and satisfaction in mastering tasks that appropriately match capabilities.

Characteristic: The capacity for learning of high-ability students is underestimated and thus becomes underdeveloped, especially if learning criteria lack sufficient challenge, and curriculum is not adequately knowledge rich and rigorous.

Implication: Curriculum must be targeted at developing especially deep and well-organized knowledge structures that with time will begin to approximate those of experts. Doing so will foster cognitive development, higher-level thinking skills, and creativity. The depth of the curriculum should allow gifted learners to continue exploring an area of special interest to the expert level. Curricula for these students should enable them to explore constantly changing knowledge and information and develop the attitude that knowledge is worth pursuing in a global society.

Characteristic: High-ability children are advanced in their critical and creative thinking skills. They tend to spend much more time up front (i.e., metacognitively) than in the execution phase of problem solving.

Implication: The basic thinking skills to be developed in high-ability students are critical thinking, creative thinking, problem finding and solving, research, and decision making. Those skills should be mastered within each content domain.

Characteristic: High-ability students prefer unstructured problems in which the task is less well defined. They also like to structure their own learning experiences. They do not require careful scaffolding of material or step-by-step learning experiences to master new material or concepts; in fact, they become frustrated with such approaches.

Implication: Opportunities to identify and solve problems should be provided. Interdisciplinarity, greater in-depth exploration of areas of interest, and autonomous learning should be encouraged. Meaningful project work in content areas, in which real-world products are generated, is appropriate as it allows students the opportunity to create on their own and to apply and expand ideas learned in class. To facilitate such work, curricula should encourage exposure to, selection of, and use of specialized and appropriate resources.

Characteristic: High-ability students have the capacity to make connections easily among disparate bodies of knowledge and to deal effectively with abstractions and complexity of thought.

Implication: Curricula ought to emphasize providing students with a deep understanding of the important concepts of a discipline and how they

are organized, as well as identify important pathways between disciplines so that separate facets of knowledge are understood as being integrated. Curricula should allow for the development and application of productive thinking skills to instill in students the capacity to reconceptualize existing knowledge and generate new knowledge.

Characteristic: Eminent persons tend to have been profoundly influenced by a single individual, such as an educator. Students in the top mathematical/science graduate programs have reported research experiences during high school at unusually high levels. Those who are precocious in creative production tend to exhibit outstanding achievement in adult life.

Implication: Mentorships, internships, or long-term research opportunities should be provided for advanced students.

Characteristic: High-ability students who become productive adults in a domain have passed through that domain's specific stages. Doing so took them much time and sustained effort, with the talent development process having begun well before secondary school.

Implication: Accelerated learning experiences are critical, given that the development of talent proceeds from practice and mastery of increasingly more difficult and complex skills at an individual rate, and mastery of a domain's knowledge base and the concomitant reorganization of cognitive structures are both necessary for creativity.

Characteristic: High-ability students develop greater expectations, feel better about themselves, and engage in higher-level processing or discourse when working with other students of similar ability.

Implication: High-ability students need the challenge and stimulation of being together for at least part of every school day, with expectations set high enough to challenge their potential ability to meet them.

7

Designing Curriculum, Instruction, Assessment, and Professional Development

The previous chapter describes seven principles that support learning with understanding. This chapter explores the implications of those principles for the intentional and systemic design of four key elements of the educational system—curriculum, instruction, assessment, and professional development—to promote learning with understanding within the context of advanced study. It is critical to recognize that programs for advanced study share many of the objectives of other programs in the same discipline; these design principles, therefore, also apply to the design and development of mathematics and science courses at all levels.

While each of the four key elements is addressed separately here, in practice they work together synergistically and need to be aligned in mutually supportive ways. Without such alignment and interdependence, deep conceptual understanding is more difficult to achieve. For example, if teachers focus on teaching “big ideas” but the related assessments measure students’ knowledge of discrete facts, it is impossible to know the extent to which students genuinely understand core concepts. The systemic and dynamic relationship among the four elements also means that changes in one element affect and require changes in the others.

In addition, it is essential to recognize the critical role of the learning environment in fostering learning with understanding. The learning environment of the school and the classroom in which these components of educational programs interact affects the degree to which teachers can integrate curriculum, instruction, and assessment to promote learning with understanding (National Research Council [NRC], 2000b).

CURRICULUM

A curriculum for understanding is intentionally designed around the organizing principles and essential concepts of the domain and provides opportunities for in-depth exploration in a variety of contexts (design principles for curriculum are summarized in Box 7-1). Such a curriculum emphasizes depth of understanding over breadth of coverage. It is designed to provide genuine opportunities for high-quality instruction and multiple points of entry into mathematics and science (Au and Jordan, 1981; Brown, 1994; Heath, 1983; Tharp and Gallimore, 1988).

Research reveals that experts' knowledge is organized around core concepts or organizing principles that guide their thinking in their area of exper-

BOX 7-1 Principles of Curriculum for Understanding

A mathematics or science curriculum for advanced study that promotes learning with understanding:

- Structures the concepts, factual content, and procedures that constitute the knowledge base of the discipline around the organizing principles (big ideas) of the domain.
- Links new knowledge to what is already known by presenting concepts in a conceptually and logically sequenced order that builds upon previous learning within and across grade levels.
- Focuses on depth of understanding rather than breadth of content coverage by providing students with multiple opportunities to practice and demonstrate what they learn in a variety of contexts.
- Includes structured learning activities that, in a real or simulated fashion, allow students to experience problem solving and inquiry in situations that are drawn from their personal experiences and real-world applications.
- Develops students' abilities to make meaningful applications and generalization to new problems and contexts.
- Incorporates language, procedures, and models of inquiry and truth verification that are consistent with the accepted practice of experts in the domain.
- Emphasizes interdisciplinary connections and integration and helps students connect learning in school with the issues, problems, and experiences that figure prominently in their lives outside of the classroom.

tise; expert knowledge is not simply a list of facts and formulas (Chi, Feltovich, and Glaser, 1981; Kozma and Russell, 1997; NRC, 2000b; see also Chapter 6, this volume). Therefore, in designing a curriculum for understanding, the key concepts and processes of the discipline should be clearly identified, explicated, and organized in a coherent fashion around the big ideas (Mintzes, Wandersee, and Novak, 1998; National Council of Teachers of Mathematics [NCTM], 1995; NRC, 1996). In addition, the interrelationships among topics should be clearly articulated to provide a framework teachers can use in developing and setting goals for their students' learning (American Association for the Advancement of Science [AAAS], 2001).

The organization of curriculum plays a critical role in helping students reconstruct misconceptions and see connections between what they are currently learning and what they have learned before. Curriculum for understanding represents more than a collection of activities or bits of information: it provides for the holistic performance of meaningful, complex tasks in increasingly challenging environments (Resnick and Klopfer, 1989). A curriculum for understanding takes the shape of topical strands that are highly interconnected in ways that are consistent with the knowledge structure used by experts in tackling complex tasks in their discipline (Marin, Mintzes, and Clavin, 2000).¹

The deep disciplinary understanding of experts encompasses a vast amount of knowledge, but generally only a subset of that knowledge is used in the solution of any given problem. Experts not only have acquired extensive and deep knowledge and conceptual understanding, but also are skilled at discerning, identifying, and retrieving knowledge that is relevant to the solution of a particular problem. Their knowledge is organized into meaningful patterns and structures and is conditionalized (situated), meaning that what they know is accompanied by a specification of the contexts in which it is useful (Glaser, 1992; Simon, 1980). Many curricula and instructional materials, however, are not designed to help students conditionalize their knowledge. For example, textbooks are more likely to tell students how to do something than to help them understand the conditions under which doing it will be useful (Simon, 1980, p. 92). Having students work in laboratory settings is a familiar strategy for helping them develop conditionalized knowledge that supports problem solving. Well-designed laboratory experiences also encourage students to apply their knowledge and skills to concrete, real-world problems or novel situations (Resnick, 1994).

¹See also the proceedings of From Misconceptions to Constructed Understanding, the Fourth International Misconceptions Seminar, at <http://www.mlrg.org/proc4abstracts.html> (November 27, 2001).

Students presented with vast amounts of content knowledge that is not organized into meaningful patterns are likely to forget what they have learned and to be unable to apply the knowledge to new problems or unfamiliar contexts (Haidar, 1997). Curriculum for understanding provides ample opportunity for students to apply their knowledge in a variety of contexts and conditions. This helps them transfer their learning to new situations and better prepares them for future learning (Bransford and Schwartz, 2000). Providing students with frequent opportunities to apply what they learn in multiple contexts requires a reallocation of instructional time. Allowing time for in-depth learning means decisions must be made about what knowledge is of most worth. For this reason, the curriculum needs to specify clearly the appropriate balance between breadth and depth of coverage in terms of student learning outcomes.

It is well accepted that students draw on their families, communities, and cultural experiences to create meaning and understanding. When curriculum is designed to build on students' experiences, teachers are able to engage students' prior knowledge, expose and restructure their knowledge and remediate misconceptions, and enhance motivation to learn. If students are able to draw on their cultural, social, and historical experiences in problem-solving situations, they are more likely to deepen their understanding. This can be accomplished by design through structured activities that, in real or simulated fashion, allow students to experience problem solving and inquiry in situations drawn from their personal experiences.

An effective curriculum allows for incorporating socialization into the discourse and practices of academic disciplines and provides frequent opportunities for students to apply the modes of inquiry and truth verification strategies and processes characteristic of each domain. An appreciation of the distinctive features of disciplines, however, should not lead to their isolation from each other or from the everyday world. Rather, strong curriculum design emphasizes interdisciplinary connections, integration, and authenticity in the relationship between learning in and out of school. These features not only make learning more challenging, exciting, and motivating, but also help students develop their abilities to make meaningful connections by applying and transferring knowledge from one problem context to another. The emphases of a curriculum for supporting learning with understanding are presented in Table 7-1.

INSTRUCTION

Instruction in advanced courses in mathematics and science should engage students in a variety of learning activities that are purposefully designed to connect with what they already know and motivate them to work

TABLE 7-1 Characteristics of Curriculum for Student Understanding

Less Emphasis on	More Emphasis on
Lists of topics to be covered	Underlying disciplinary principles and processes sequenced to optimize learning
Isolated concepts presented in relation to a single context or topic with no connection to other topics	Continuity and interdisciplinary integration through emphasis on the relationships of unifying concepts and processes to many topics
Individual teachers working in isolation	Collaborative teams including content and pedagogy experts
Coverage of as many topics as possible in a limited and fixed amount of time Example: A curriculum guide specifies that 8 percent of the advanced biology course should include topics related to cell energy, including cellular respiration and photosynthesis. The teacher schedules 1 week for a unit on cellular respiration. During this time, students carry out a variety of activities and laboratory exercises in class and complete out-of-class assignments. At the end of the week they take a unit test. The class goes on to the next unit, photosynthesis.	Understanding of concepts in expanded and more flexible time periods Example: A curriculum specifies four statements of essential knowledge about the production and utilization of energy in cells that are critical to building an understanding of the processes of photosynthesis and respiration. Prior relevant knowledge possessed by students is assessed using quizzes or student concept maps. The teacher schedules 3 days for activities that focus on this knowledge. A rubric is written so that both teacher and students know how the knowledge will be demonstrated. Students carry out a variety of activities in class and complete out-of-class assignments. At the same time, they must demonstrate their knowledge of each of the four specified outcomes before they can receive credit for the unit. Students continue to work on essential knowledge and present evidence when they are ready, even as activities for the next unit may be beginning.
Curriculum developed for one course at a time without articulation among the levels of schooling	Curriculum that is well articulated between the elementary grades and between high school and college and makes recognized connections with other disciplines
A rigid, prescribed, static curriculum	Curriculum that can be adapted to meet the diverse needs of students and situations
No relationship between NRC's <i>National Science Education Standards</i> /NCTM's <i>Principles and Standards for School Mathematics</i> and programs for advanced study or college courses	Standards-driven changes in courses, leading to advanced high school and introductory college courses through modification of content and pedagogy at the advanced course and college levels

SOURCES: Adapted from ACS (1997); NRC, (1996); and NSTA, (1996).

toward developing deeper understanding. Instruction should focus students on the central concepts and fundamental principles of the discipline. It also should assist them in constructing a framework for organizing new information as they explore concepts in depth and in a variety of contexts and develop problem-solving strategies common to the discipline (Novak, 1991). The design principles for instruction are summarized in Box 7-2.

BOX 7-2 Principles of Instruction for Understanding

Teaching for conceptual understanding in advanced mathematics and science courses:

- Maintains students' focus on the central organizing themes and underlying concepts of the discipline.
- Is based on careful consideration of what students already know, their ideas and ways of understanding the world, and the patterns of practice they bring with them into the classroom.
- Focuses on detecting, making visible, and addressing students' often fragile, underdeveloped understandings and misconceptions.
- Reflects an understanding of differences in students' interests, motivations, preferences, knowledge, and abilities.
- Is designed to provide the appropriate degree of explicitness for the situation and the abilities of the learners.
- Recognizes students' preferences for and varying abilities to process different symbol systems, such as language (written and spoken), images, and numerical representations, by employing multiple representations during instruction.
- Engages students in worthwhile tasks that provide access to powerful mathematical and scientific ideas and practices; moves students to see past the surface features of problems to the deeper, more fundamental principles; and develops their conceptual understanding and skills.
- Structures learning environments in which students can work collaboratively to gain experience in using the ways of thinking and speaking used by experts in the discipline.
- Orchestrates classroom discourse so that students can make conjectures, present solutions, and argue about the validity of claims, thus helping them explore old understandings in new ways, reveal misconceptions, and generalize and transfer their learning to new problems or more robust understandings.
- Provides explicit instruction in metacognition as part of teaching in the discipline.
- Uses various kinds of formal and informal formative assessments to monitor students' understanding and target instruction effectively.
- Creates expectations and social norms for the classroom that allow students to experience success and develop confidence in their abilities to learn.

The selection of instructional strategies and activities should be guided by knowledge of learners and should recognize and build on individual differences in students' interests, understandings, abilities, and experiences. Instruction should take into account common naive concepts held by students, as well as the effects of their cultural and experiential backgrounds on their learning. It also should reflect the teacher's own strengths and interests and consideration of available local resources. Activities and strategies should be continually adapted and refined to address topics arising from student inquiries and experiences.

It is important for instruction in advanced courses in mathematics and science to engage students in inquiry using a variety of activities and strategies, including experimentation, critical analysis of various sources of information, and the application of technology in problem solving. In this way, students combine knowledge in the domain with reasoning and thinking skills as they are engaged collaboratively in asking questions, constructing, testing and analyzing explanations, communicating the explanations, and considering alternatives (Townes and Grant, 1997).

One of a teacher's primary responsibilities is to select and develop significant and meaningful problems, learning experiences, projects, and investigations for students. Learning experiences are worthwhile when they represent concepts and procedures; foster skill development, reasoning, and problem solving; and help students make connections among mathematical and scientific ideas and to real-world applications (NCTM, 1991). Such experiences prompt the learner to see past the surface features of a problem to deeper, more fundamental principles. They "lend themselves to multiple solution methods, frequently involve multiple representations, and usually require students to justify, conjecture, and interpret" (Silver and Smith, 1996, p. 24). The design of such tasks is complex, requiring teachers to take account of students' knowledge and interests, of the ways students learn particular mathematical or scientific ideas, and of common points of confusion and misconceptions about those ideas (Borko et al., 2000).

Accomplishing this complex endeavor requires a qualified teacher. The National Board for Professional Teaching Standards (NBPTS) describes a qualified teacher as one who effectively enhances student learning and demonstrates the high level knowledge, skills, abilities, and commitments reflected in the following five core propositions:²

- Teachers are committed to students and their learning.
- Teachers know the subjects they teach and how to teach those subjects to students.

²See <http://www.nbpts.org> (November 22, 2001).

- Teachers are responsible for managing and monitoring student learning.
- Teachers think systematically about their practice and learn from experience.
- Teachers are members of learning communities.

To promote understanding, explicit instruction in metacognition should be integrated into the curriculum. Thus, instruction should create tasks and conditions under which student thinking can be revealed so that students, with their teachers, can review, assess, and reflect upon what they have learned and how. Additionally, teachers should make their reasoning and problem-solving strategies visible to students whenever possible (Collins and Smith, 1982; Lester et al., 1994; Schoenfeld, 1983, 1985).

Effective instruction in advanced courses should involve building and nurturing a community of learners. A community of learners encourages students to take academic risks by providing opportunities for them to make mistakes, obtain feedback, and revise their thinking while learning from others with whom they are engaged in inquiry and cooperative problem-solving activities.

To nurture the capacity of students to generalize and transfer their learning to new problems, teachers must help students explore old understandings in new ways. To this end, teachers must draw out misconceptions in order to challenge and displace them (Blumenfeld, Marx, Patrick, Krajcik, and Soloway, 1997; Caravita and Hallden, 1994; Jones, Rua, and Carter, 1998; NRC, 2000b; Pearsall, Skipper, and Mintzes, 1997;).

Since intrinsic motivation is self-sustaining, instruction should be planned so as to maximize the opportunity for developing a strong intrinsic motivation to learn. Students benefit when they can experience success and develop the confidence of a successful learner—one who has the tools to ask relevant questions, formulate problems and reframe issues, and assess his or her own knowledge and understanding (Alaiyemola, Jegede, and Okebukola, 1990; Stipek, 1998). Table 7-2 illustrates the emphases of instructional practices to support learning with understanding.

ASSESSMENT

Educational assessments can be designed for any number of purposes, from conducting large-scale evaluations of multiple components of educational programs to measuring individual students' mastery of a specified skill. Understanding assessment results requires that the user draw inferences from available data and observations that are supported by the assessment. Three key concepts related to assessments—reliability, validity, and fairness—underlie a user's ability to draw appropriate inferences from the

TABLE 7-2 Characteristics of Instruction for Student Understanding

Less Emphasis on	More Emphasis on
Presenting scientific knowledge through lecture, text, and demonstration, with activities centered on the teacher	Guiding students through active and extended inquiry and facilitating student-centered learning
The same learning experiences for all students	Appropriate matching of strategies and learners based on awareness of individual student's prior knowledge, abilities, and interests
Strategies that have students working alone	Strategies that incorporate collaboration among students and foster the development of classroom learning communities
"One-size-fits-all" instructional strategies	Multiple strategies designed to enhance understanding
Establishing blocks of time and designing lessons such that all students are required to learn the same thing in the same way at the same rate	Flexible scheduling and learning experiences that provide students with enough time, space, resources, guidance, and feedback for learning
Students doing numerous, often simplistic and unconnected laboratory activities and being exposed to many different procedures	Students conducting extended investigations and inquiry and having opportunities to progress through cycles of assessment and revision
Focusing on elaborate, equipment-intensive laboratory exercises	Focusing on interactions between students and materials, as well as teacher-student and student-student interactions
Laboratory exercises in which students are provided with all relevant background and procedures and are asked to follow the steps, fill in the data, and answer a few questions, after which the class moves on	Laboratory and inquiry experiences in which students are challenged to formulate questions that can be answered experimentally, propose and support hypotheses, plan procedures, design data tables and data analyses, evaluate and discuss results, and repeat experiments with modifications
Teachers monitoring laboratory work to ensure that the steps of the procedure are being followed correctly	Teachers acting as facilitators for laboratory experimentation; advising students on what essential measurements must be taken; discussing sample sizes; suggesting equipment that is available for use during the experiment; coaching students in techniques and protocols; and, within the limits of safety, allowing students to make mistakes and try again
Example: The teacher's lecture centers on presenting and explaining rate expressions and factors that affect forward and reverse reactions. K_{eq} calculations are shown. The teacher demonstrates color changes in a reversible reaction. LeChatelier's principle is reviewed, and students predict equilibrium shifts on the basis of hypothetical changes in reactants, products, and conditions. Student misconceptions about the nature of equilibrium remain uncovered and unchallenged.	Example: The teacher poses a question: "If the rate of a forward reaction is faster than the rate of a reverse reaction, will the system ever come to equilibrium?" Students are asked to construct a model for such a system, in which particles can be moved between two containers at different rates, and to use this model to collect data needed to answer the question. The common student misconception that equilibrium means equal amounts in each container is challenged as students develop an understanding of the principle of equilibrium.

SOURCES: Adapted from ACS (1997); NRC (1996); NSTA (1996).

results. A brief discussion of each is provided in Box 7-3 (for further detail see, American Educational Research Association [AERA]/American Psychological Association [APA]/National Council on Measurement in Education [NCME], 1999; Feldt and Brennan, 1993; Messick, 1993; NRC, 1999b).

Assessment is a critical aspect of effective teaching and improved education (NBPTS, 1994; NCTM, 1995; NRC, 2001a; Shepard, 2000). It is important to note, however, that assessment does not exist in isolation, but is closely linked to curriculum and instruction (Graue, 1993). Thus as emphasized earlier, curriculum, assessment, and instruction should be aligned and integrated with each other, and directed toward the same goal (Kulm, 1990; NCTM, 1995; Shepard, 2000). In advanced mathematics and science, that goal is learning with understanding.

This section reviews design principles for two types of assessments: those that measure student achievement at the end of a program of study, such as AP Physics, and those that are used by teachers to provide feedback to students, guide instruction, and monitor its effects throughout the course of study (see Box 7-4 for a summary of the design principles for assessment). To guide instruction, teachers need assessments that provide specific

BOX 7-3 Reliability, Validity, and Fairness

Reliability generally refers to the stability of results. For example, the term denotes the likelihood that a particular student or group of students would earn the same score if they took the same test again or took a different form of the same test. Reliability also encompasses the consistency with which students perform on different questions or sections of a test that measure the same underlying concept, for example, energy transfer.

Validity addresses what a test is measuring and what meaning can be drawn from the test scores and the actions that follow (Cronbach, 1971). It should be clear that what is being validated is not the test itself, but each inference drawn from the test score for each specific use to which the test results are put. Thus, for each purpose for which the scores are used, there must be evidence to support the appropriateness of inferences that are drawn.

Fairness implies that a test supports the same inferences from person to person and group to group. Thus the test results neither overestimate nor underestimate the knowledge and skills of members of a particular group, for example, females. Fairness also implies that the test measures the same construct across groups.

BOX 7-4 Principles of Assessment for Understanding

The following principles of assessment can be applied both to assessments designed to assist learning (curriculum-embedded or formative assessments) and those designed to evaluate student achievement at the end of a unit of study (summative assessments). Effective assessments for measuring students' learning with understanding in advanced mathematics and science are:

- Based on a model of cognition and learning that is derived from the best available understanding of how students represent knowledge and develop competence in a domain.
- Designed in accordance with accepted practices that include a detailed consideration of the reliability, validity, and fairness of the inferences that will be drawn from the test results (see Box 7-3). This is especially important when the assessment carries high stakes for students, teachers, or schools.
- Aligned with curriculum and instruction that provide the factual content, concepts, processes, and skills the assessment is intended to measure so the three do not work at cross-purposes.
- Designed to include important content and process dimensions of performance in a discipline and to elicit the full range of desired complex cognition, including metacognitive strategies.
- Multifaceted and continuous when used to assist learning by providing multiple opportunities for students to practice their skills and receive feedback about their performance.
- Designed to assess understanding that is both qualitative and quantitative in nature and to provide multiple modalities with which a student can demonstrate learning.

information about what their students are learning and what they do and do not understand. Of primary importance if a test is to support learning is that students be given timely and frequent feedback about the correctness of their understandings; in fact, providing such feedback is one of the most important roles for assessment. There is a large body of literature on how classroom assessment can be designed and used to improve learning and instruction (see for example, Falk 2000; Shepard 2000; Wiggins, 1998; Niyogi, 1995). Concept maps, such as those discussed in Box 6-2 in Chapter 6, are one example of an assessment strategy that can be used to provide timely

and informative feedback to students (Edmondson, 2000; Rice, Ryan, and Samson, 1998).

End-of-course tests are too broad and too infrequently administered to provide information that can be used by teachers or students to inform decisions about teaching or learning on a day-to-day basis. The power of such tests lies in their ability to depict students' attainment of larger learning goals and to provide comparative data about how the achievement of one student or one class of students compares with that of others.³ Ultimately, end-of-course tests are often used to shape teachers' instructional strategies in subsequent years. Thus, the content of the tests should be matched to challenging learning goals and subject matter standards and serve to illustrate what it means to know and learn in each of the disciplines.

Because advanced study programs in the United States are strongly influenced by high-stakes assessment, the committee is especially concerned with how this form of assessment can be structured to facilitate learning with understanding. It is well known that such assessments, even coming after the end of instruction, inevitably have strong anticipatory effects on instruction and learning. Thus if high-stakes assessments fail to elicit complex cognition and other important learning outcomes, such as conceptual understanding and problem solving, they may have negative effects on the teaching and learning that precede them. In designing such assessments, then, both psychometric qualities and learning outcomes should be considered.

If end-of-course tests are to measure important aspects of domain proficiency, test makers need to have a sophisticated understanding of the target domain. They must understand the content and the process dimensions that are valued in the discipline and then design the test to sample among a broad range of these dimensions (Millman and Greene, 1993). Doing so is complicated, however, by the fact that an assessment can only sample from a large universe of desirable learning outcomes and thus can tap but a partial range of desirable cognitions. Consequently, concerns will always arise that a particular assessment does not measure everything it should, and therefore the inferences drawn from it are not valid. Similarly, the selection of tasks for an assessment may be criticized for measuring more than is intended; an example is word problems on mathematics tests that require high levels of reading skill in addition to the mathematics ability that is the target of the assessment. To ensure the validity of inferences drawn from tests, a strong program of validity research must be conducted on all externally designed and administered tests. The higher the stakes of the test, the more critical is this research and the more frequently it must be reviewed (AERA/APA/NCME, 1999).

³In the case of such tests as the AP and IB examinations, the results are used additionally to guide decisions about college placement and credit.

Test design and construction includes consideration of which forms of complex thinking fairly reflect important aspects of domain proficiency. Assessments that invoke complex thinking should target both general forms of cognition, such as problem solving and inductive reasoning, and forms that are more domain-specific, such as deduction and proof in mathematics or the systematic manipulation of variables in science. Because metacognition is such an important component of experts' performance, both classroom-based and end-of-course assessments should be designed to evaluate students' use of metacognitive strategies (NRC, 2001a).

Given that the goals of curriculum and assessment for advanced study are to promote deep understanding of the underlying concepts and unifying themes of a discipline, effective assessment should reveal whether students truly understand those principles and can apply their knowledge in new situations. The ability to apply a domain principle to an unfamiliar problem, to combine ideas that originally were learned separately, and to use knowledge to construct new products is evidence that robust understanding has been achieved (Hoz, Bowman, and Chacham, 1997; Perkins, 1992).

Meaningful assessment also includes evidence of understanding that is qualitative and quantitative in nature, and provides multiple modalities and contexts for demonstrating learning. Using multiple measures rather than relying on a single test score provides a richer picture of what students know and are able to do. The characteristics of assessments that support learning with understanding are presented in Table 7-3.

TEACHER PROFESSIONAL DEVELOPMENT

One of the most important factors influencing student achievement, if not the most important, is teacher expertise (see Shepard, 2000; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Center for Education Statistics [NCES], 2000a; Darling-Hammond, 2000). Thus, the key to implementing the committee's vision of learning with deep conceptual understanding is having highly skilled teachers who can effectively put into practice the strategies suggested earlier in the discussion of instruction for understanding. This observation is particularly true when one is implementing well-structured external programs that build on the regular curriculum already in place at a school. Most teachers, even those regarded as excellent, would have to change their beliefs and practices significantly to teach in a manner consistent with the committee's conceptual framework (Haidar, 1997; Jones et al., 1998; Ryder, Leach, and Driver, 1999; Schoon and Boone, 1998; Southerland and Gess-Newsom, 1999). Such change cannot occur unless teachers are given ample opportunity and support for continual learning through sustained professional development, as

TABLE 7-3 Characteristics of Assessment for Understanding

Less Emphasis on	More Emphasis on
Summative examinations—unit tests and the final examination	Formative assessments—ongoing assessment of teaching and learning
High-stakes tests that impact college entrance and placement and drive unintended program change	Learning assessments that drive program changes in the direction of the goal for advanced studies
Assessments that measure students' ability to recall facts	Assessments that evaluate understanding and reasoning
Assessment as something that is done to students and that provides information to teachers about students	Students participating in developing and analyzing the results of assessments
Private communication of students' ideas and understandings to the teacher/examiner	Classroom discourse including argument and explanation of students' ideas and understandings
<p>Example: During a unit on cell structure, biology students participate in lecture/discussions, complete reading assignments, use electron micrographs to examine cell ultrastructure, and conduct related practical investigations involving microscopic examination of a variety of cell types and scale drawings. At the end of the unit laboratory write-ups are collected, and a unit test is administered.</p>	<p>Example: Students participate in varied assessment activities throughout the unit. A brief oral examination tests understanding of a reading assignment. A teacher uses a check sheet during microscope work to assess skills. Laboratory data records are evaluated individually as the students are working on the investigations. A short multiple-choice test on identifying and naming cell parts is given, marked, and discussed. Students prepare a concept map illustrating the relationship between cell structure and function and are asked to explain their thinking to a small group. The group gives feedback, and each student performs a self-assessment of the quality of his or her concept map. The class develops a rubric that will be applied to a unit examination essay question comparing prokaryotic and eukaryotic cell structures. A unit test, of which the essay is one component, is given.</p>
Assessing discrete, easily measured information	Assessing what is most highly valued—deep, well-structured knowledge
<p>Example: A multiple-choice question asking students to select the weak base given a set of chemical formulas.</p>	<p>Example: A free-response question involving this scenario: The student is given four 0.10 M solutions labeled A, B, C, D; a conductivity probe; and a pH probe. One of the solutions is a weak acid, one a strong acid, one a weak base, and another a strong base. The student is asked to characterize each solution, describing both the method developed to solve the problem and the results.</p>
Student dependence on using algorithms	Students communicating thought processes
One right or wrong answer	Partial credit for various subtasks and many possible paths to a successful outcome
Unintended uses of results	Clear relationships between the decisions and the data

SOURCES: Adapted from ACS (1997); NRC (1996); NSTA (1996).

well as the opportunity to try out and reflect upon new approaches in the context of their own classrooms (Putnam and Borko, 1997).

Because the standards and frameworks driving reform efforts do not provide specific guidelines for teaching, the implementation of reform visions, including that described in this report, poses a considerable challenge for teachers and school administrators responsible for curriculum and instruction. Moreover, the changes demanded of teachers are not a simple matter of learning new teaching strategies: “Learning to practice in substantially different ways from what one has oneself experienced can occur neither through theoretical imaginings alone nor unguided experience alone” (Darling-Hammond, 1999a, p. 227). Thus the success of current reform efforts—in secondary mathematics and science, as well as other curricular areas—in fostering learning with understanding depends on creating opportunities for teachers’ continual learning and providing sufficient professional development resources to exploit these opportunities (Darling-Hammond, 1996, 1999b; Sykes, 1996).

Unfortunately, current professional development for U.S. teachers can be described only as inadequate:

Sadly and short-sightedly, however, professional development is too often treated not as a necessity but as a luxury item on the school budget. Many people erroneously believe that teachers are not working unless they are standing in front of a classroom. In fact, preparation time, individual study time, as well as time for peer contact and joint lesson planning, are vital sources of both competence and nourishment for all teachers. But teachers are granted precious little time for any of these activities. . . . High quality professional development ought to be the lifeblood of American teaching; instead, it is used only to provide the occasional transfusion. (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, p. 27)

Nothing has promised so much and been so frustratingly wasteful as the thousands of workshops and conferences that led to no significant change in practice when teachers returned to their classrooms. (Fullan, 1991, p. 315)

To teach advanced mathematics or science well, teachers need to know their subjects deeply and extensively, know their students and understand how they learn, and know the pedagogical techniques specific to their subjects. These three domains of professional knowledge form the core content of professional development for teachers (NCTM, 2000; Schulman, 1986). Teachers use this knowledge to listen carefully to students and examine their work in order to identify understandings and misunderstandings and frame appropriate learning activities for each student (NCTM, 1991; NRC, 1996). Box 7-5 summarizes the design principles for professional development of teachers.

BOX 7-5 Principles of Effective Professional Development

Effective professional development for teachers of advanced study in science and mathematics:

- Focuses on the development of teachers' subject matter knowledge, knowledge of students, and subject-specific pedagogical knowledge.
 - Emphasizes deep conceptual understanding of content and discipline-based methods of inquiry.
 - Provides multiple perspectives on students as learners.
 - Develops teachers' subject-specific pedagogical knowledge.
- Treats teachers as active learners who construct their own understandings by building on their existing knowledge and beliefs.
 - Is grounded in situations of practice.
 - Takes place in professional communities where teachers have the opportunity to discuss ideas and practices with colleagues.
 - Uses with teachers' instructional strategies and assessment practices that teachers are expected to use with students.
 - Is most effective when teachers take an active role.
 - Is an ongoing, long-term effort spanning teachers' professional lives.

Professional development should emphasize more than the fundamental facts, concepts, and procedures of a discipline. It also should help teachers understand the particular methods of inquiry in their discipline, know discipline-specific ways to reason and communicate, and understand the relationships of the discipline to other school subjects and to societal issues (NCTM, 1991; NRC, 1996).

Professional development should also help teachers understand students as learners by providing opportunities to examine students' thinking about mathematics and science. Excellent professional development addresses such issues as how students think and behave, what they already know and believe, and what they find interesting. Issues of race, gender, age, and socioeconomic background also are germane, as is an understanding of students' common preconceptions and misconceptions. In addition, teachers should expect to receive a strong foundation of pedagogical content knowledge from effective professional development. Such knowledge might include instructional and classroom organization strategies, materials and resources

(including technology), alternative ways to represent concepts and strategies or assess student understanding, and methods of fostering classroom discourse and communication.

High-quality professional development treats teachers as teachers should treat their students, including acknowledging that learning is an active process wherein learners construct new understandings based on what they already know and believe. There is considerable evidence that existing knowledge and beliefs play an important role in how teachers learn to teach, how they teach, and how they think about teaching in new ways (Cohen and Ball, 1990; Prawat, 1992; Putnam and Borko, 1997). If professional development is to support meaningful change in teaching and teachers, it must address teachers' existing knowledge and beliefs, just as teachers are expected to address prior knowledge in their students in order to promote learning with understanding. What teachers know and believe will influence their interpretation and enactment of new ideas for teaching.

Moreover, professional development instructors are role models who contribute to teachers' evolving visions of what and how to teach. Although they ought to model the kinds of practices they expect teachers to use in their own classrooms, all too often teacher educators, like K–12 educators, revert to what they know best—the ways they were taught themselves. The result is professional development activities that promote traditional views of schooling and uninspired, didactic teaching methods.

Because knowledge is integrally connected with the contexts in which it is acquired and used, teacher learning ought to be situated in practice. There are numerous ways to accomplish this, with advantages for different components of teacher learning (Putnam and Borko, 1997). One approach is to conduct professional development at the schools—and largely in the classrooms—where participants teach. Doing so enables the teacher and staff developer to work together to interpret classroom events in light of various ideas about teaching, learning, and subject matter. A second approach is to have teachers bring experiences from their classrooms, such as samples of students' work or videotapes of classroom activities, to workshops. Away from the classroom, teachers have opportunities to develop a reflective perspective on teaching by considering different points of view on their own teaching practice and that of others. Other activities, such as detailed study of the discipline, may best occur away from the classroom. Settings such as summer workshops free teachers from the daily demands of having to think about the immediate needs of their students and classrooms.

A combination of experiences situated in different settings may be the most powerful way to foster meaningful change in teachers' thinking and practice (Putnam and Borko, 1997). The recommendations of the National Commission on Mathematics and Science Teaching for the 21st Century (2000)

provide one model for multifaceted professional development. Central to the commission's recommendations are summer institutes designed to address pressing needs, such as enhancing teachers' subject matter knowledge, introducing new teaching methods, and integrating technology into teaching. Also recommended are ongoing inquiry groups. Teachers need to form learning communities in which they can explore problems of practice that occur during the school year and engage in continuing discussion to enrich their knowledge of subject matter, students, and teaching.

Professional development, as characterized here, typically occurs in professional communities, not in isolation. This model is consistent with a view of cognition as developing within a social context that provides the language, concepts, and modes of thought with which people make sense of the world. If teachers are to be successful in developing new practices, they need opportunities to participate in, as McLaughlin and Talbert (1993, p. 15) put it, "a professional community that discusses new teacher materials and strategies and that supports the risk taking and struggle entailed in transforming practice." Through their participation in such professional communities, as well as through other means of communication, such as books, professional journals, and electronic networks, teachers come to understand and think in ways that are common to those communities while also helping the thinking of the community to develop and change.

Because learning is a developmental process that takes time and hard work, teachers' professional development needs to continue throughout their careers, and teachers need to accept responsibility for their own learning and growth. If teachers view themselves as agents of change, responsible for improving teaching and learning in their schools, they may be more likely to take advantage of high-quality professional development. Professional development, in turn, should support and encourage teachers in accepting such responsibilities.

In sum, tomorrow's students will have very different needs from those of today as a result of new knowledge in the various disciplines, new technologies, and new workplace demands. To meet those needs, teachers must constantly revise their practice and reflect on teaching and learning. To this end, teachers need professional development that provides opportunities for them to expand their knowledge, to experiment with new ideas about teaching and learning, to receive feedback about their teaching, and to work with others to effect positive changes in mathematics and science education (NCTM, 1991; NRC, 1996; Putnam and Borko, 1997). Lifelong learning experiences can provide teachers with the opportunity to continually consider and contribute to the evolving knowledge base of teaching and learning (NRC, 1996). Table 7-4 summarizes the emphases of professional development programs that promote understanding.

TABLE 7-4 Characteristics of Effective Teacher Professional Development

Less Emphasis on	More Emphasis on
Sporadic learning opportunities	Continuous ongoing, connected learning experiences
Transmission of knowledge and skills by lecture	Inquiry into teaching and learning
Isolation of teachers, classrooms, and disciplines	Interdisciplinary inquiry that extends beyond the classroom
Separation of science/mathematics content knowledge and teaching knowledge	Discipline-specific pedagogy
Separation of theory and practice	Integration of theory and practice in school settings
Individual learning, as teachers of an advanced subject are physically and temporally isolated from other teachers of the same advanced subject	Collegial and collaborative learning in a professional community and time for teachers to interact during the school day and year
Teacher as technician and consumer of knowledge	Teacher as reflective practitioner and producer of knowledge
Teacher as target of change	Teacher as source and facilitator of change
Reliance on external or internal expertise only	Mix of internal and external expertise
Fragmented, one-shot workshops	Long-term, coherent plans incorporating 1- to 2-week summer institutes with follow-up during the school year

SOURCES: Adapted from ACS (1997); NRC (1996); NSTA (1996).

FROM FRAMEWORK TO ADVANCED STUDY PROGRAMS

The development of educational programs that foster learning with conceptual understanding, as outlined in this chapter, could be seen as idealization that cannot be achieved in practice; the committee sees it as an imperative. The changes in education proposed here represent a significant departure from current practice in most schools and from most of the preparation and professional development that teachers and school administrators have received. Implementing such changes will not require reforming, but rather transforming the entire social and institutional context for learning, including school culture, leadership practices, and pedagogical practice. The more aligned the institutional and social context for learning is with the committee's conceptual framework for analyzing and designing advanced study, the more likely it is that the innovations we advocate will be sustained over time and enhance student achievement.

The committee has come to a sobering conclusion: given what is now known about human learning, transformation of advanced study is imperative. Accordingly, the committee presents in this report a framework and a set of guidelines for assessing and designing advanced study. This framework was constructed on the basis of current knowledge about how people learn and about the nature of subject matter expertise. Advanced study programs that are aligned with this framework and the attendant principles will foster deep, robust conceptual understanding. They also will make such deep learning accessible to a broader range of students, because the principles of learning and of program design set forth here (1) recognize multiple ways of thinking and (2) support a wide range of perspectives and practices in the school curriculum. The complex, authentic, multidimensional learning opportunities that could be designed following the committee's model could make it possible for all children to discover and use their unique strengths to engage in learning at a deep conceptual level.



Analysis of the AP and IB Programs Based on Learning Research

In this chapter, what is known about how people learn, especially the principles of learning presented in Chapter 6, is used as a lens for analyzing and assessing the Advanced Placement (AP) and International Baccalaureate (IB) programs in mathematics and science. In Chapter 9, this analysis is extended with respect to the design principles of curriculum, instruction, assessment, and professional development presented in Chapter 7. The analysis highlights some major strengths and shortcomings in the programs as currently implemented in U.S. high schools and indicates directions for change that would help bring the program elements into closer alignment with the principles of learning set forth in Chapter 6 and with the goals of advanced study. Although the analysis is often critical, the committee recognizes that these advanced programs challenge some of the nation's most talented and highly motivated students and some of its most capable and creative high school teachers to accomplish more than is generally expected of a high school education. Both programs have provided models of high expectations for students and of recognized and valued external assessments of student achievement. Regular and even honors courses are often not sufficiently challenging for many of the best students in the sciences and mathematics.

The AP and IB programs are dynamic and were moving toward significant change even as the present study was being conducted, as exemplified by the report of the Commission on the Future of the Advanced Placement Program (CFAPP) (2001) and the revision of the IB Experimental Sciences curriculum, discussed in Chapters 3 and 4, respectively. Both programs are being adapted to serve broader purposes than those for which they were originally designed. Sometimes, however, the programs are misused through no fault of their developers, as discussed in Chapter 10.

Another set of caveats is in order. Neither the College Board nor the International Baccalaureate Organisation (IBO) articulates the principles of learning on which its program is based. This is understandable, as both

programs were created well before the nature of human cognition and learning became the focus of intensive research or the potential for using this research to inform the design of educational programs was emphasized. Nonetheless, now that research is providing a clearer picture of how people learn, it is important to use this information to consider how to improve the programs' courses, assessments, and professional development activities.

Systematic information is lacking about the AP and IB programs as they are actually implemented in U.S. high schools, including the instructional strategies used in individual classrooms, the structure of the syllabi in different schools, the quantity and quality of the facilities available, the preparation of teachers who teach the courses, and the ways in which students are prepared prior to advanced study.¹ What is known, however, is that there is wide variation among teachers and schools. Yet data on the nature of this variation and its effect on student learning are scant, as is information about the cognitive processes elicited by the AP and IB assessments. Because important data about the programs have not yet been published by either the programs or independent researchers, the committee focused its analysis on what the programs say they do, using available program materials such as course guides, released examinations, teacher manuals, program goals and mission statements, and expert testimony from program officials and experienced AP and IB teachers.²

The discussion in this chapter is organized around the seven principles of learning set forth in Chapter 6 and is based on the evidence noted above, as well as the findings of the four panels that conducted in-depth appraisals of the AP and IB programs in mathematics, biology, chemistry, and physics for this study.³ The analysis is focused on determining the extent to which the AP and IB curricula in science and mathematics and the associated instruction and assessments are aligned with the principles of learning and goals for advanced study outlined in previous chapters. This analysis (and that of Chapters 9 and 10) serves as the foundation for the recommendations offered in Chapter 11 for improving advanced study in general and the AP and IB programs in particular. In presenting these analyses, we emphasize that AP and IB are different programs designed for different purposes, and

¹The College Board is beginning to undertake some new research related to how the AP courses are implemented in schools. See www.collegeboard.org/ap/research/index.html (November 28, 2001). The IBO has also established a research committee to oversee studies on the nature of learning in IB classrooms. See www.ibo.org (February 8, 2002).

²The College Board and the IBO provided the committee with a considerable range of program materials, such as mission statements; course outlines; teacher guides; sample syllabi; released examinations; scoring rubrics; and research results from studies conducted under the auspices of their researchers, as well as by independent researchers.

³A summary of the panels' findings and recommendations is given in Appendix A; and the full panel reports are available online at www.nap.edu/catalog/10129.html.

therefore that findings related to one program do not necessarily apply to the other.

PRINCIPLED CONCEPTUAL KNOWLEDGE

A vital goal of advanced study is to help students progress from novice understanding toward deeper understanding of the fundamental content and unifying concepts of a discipline and toward greater expertise in the processes of inquiry and problem solving. Because they lack an organizing structure, novices tend to approach problems by seeking formulas or algorithms they have used in the past, by focusing on surface features of the problems, or by relying on their intuitions and preconceptions. Experts, on the other hand, think in terms of core concepts and underlying principles in approaching and solving problems. The evidence gathered for this report indicates that, in constructing their programs, AP and IB do not make adequate use of what is known about differences in the ways in which experts and novices structure knowledge. The committee's findings in this area are based on several key observations about the programs.

Breadth Versus Depth

According to the mathematics panel, the breadth of coverage in AP Calculus is appropriate. The curriculum for the IB Mathematical Methods Standard Level (SL) and Mathematics Higher Level (HL) courses, however, encompasses an introduction to elementary calculus (similar to the AP program's AB-level calculus course) and additional areas of study that the teacher selects from among available options. The small number of hours suggested for study of each topic (20 hours for Mathematical Methods SL and 50 hours for Mathematics HL according to the IBO's 1998 course descriptions) leads to the concern that students study each topic only at a procedural level.

The inclusion of too much content is a major issue in the sciences, especially the AP sciences. The 2-year format of the IB HL science courses makes the issue of breadth of content coverage less of a concern for these courses. However, the 1-year IB SL science courses suffer from some of the same shortcomings as the AP science courses in this regard.

The content that is expected to be taught and ultimately assessed in the final examinations for many of the AP and IB HL science courses is quite broad. According to the findings of the biology, physics, and chemistry panels, most teachers, especially AP teachers, find they have insufficient time for more than superficial coverage of some topics before moving on to others. These three science panels are unanimous in expressing their concern that,

in an effort to prepare students for an examination by covering all of the topics on the course outline, teachers may place undue emphasis on the presentation and memorization of disconnected facts.

In the science disciplines, both AP and IB materials emphasize concepts, key ideas, and unifying themes. However, the biology, chemistry, and physics panels emphasize that this commitment is largely unrealized in the programs' assessments. Although the science panels find that the examinations do not adequately assess depth of conceptual understanding and place disproportionate emphasis on recall, the panels are encouraged by the fact that the College Board is moving toward making improvements in this area. The 2002–2003 AP biology course description states, "Questions on future AP Biology Examinations can be expected to test students' ability to explain, analyze, and interpret biological processes and phenomena more than their ability to recall specific facts" (College Entrance Examination Board [CEEB] 2001a, p. 7). Although the IB examinations sample the range of assessment statements included in the syllabus for each course, the science panels cite as weaknesses what they consider to be undue emphasis on factual knowledge and failure to target misconceptions and adequately measure conceptual understanding.

In their review of the influence of external tests on the curricula provided in the schools of several nations, Madaus and Airasian (1978) conclude that "most studies have found that the proportion of instructional time spent on various objectives was seldom higher than the predicted likelihood of their occurrence on the external exam" (p. 21). Since both AP and IB courses are designed to prepare students for high-stakes, end-of-course assessments, an instructional focus on "big ideas" will likely remain unrealized until these assessments focus on key concepts in each domain, as has occurred to a considerable extent in AP calculus.

When an advanced course occupies only a single year, as in the AP program, the broad scope of the curriculum and the demands of the assessments can create a conflict between two goals: providing the broad base of content knowledge that is perceived to be necessary for the exam, and promoting conceptual understanding that provides the framework for future learning and application of knowledge. Program developers can continue to address this issue by devising focused curricula and by working to equip teachers to make judgments that support depth of understanding.

Organizing Complex Content

A second observation of the committee and the panels is that the topic outlines for AP and IB science courses sometimes provide insufficient guidance to teachers about how to organize the enormous amount of recom-

mended content around important central ideas. The course objectives are not uniformly structured to reflect the organizing themes of the discipline; each objective is presented in isolation, rather than as part of a larger network. Yet it is precisely this network—the connections among objectives—that is important (National Research Council [NRC], 2000b).

In biology, for example, although the AP course description explicitly addresses principles and themes, teachers are merely given a brief, open-ended framework for conceptual knowledge using themes that cut across different topics and must organize the content themselves. The committee is concerned that students, given the sheer volume of material with which they are confronted in a typical AP biology course, may be unable to use the organizing themes effectively, even when they know what those themes are. Being able to state a theme or memorize a statement is a far cry from understanding it.

The IB Biology Guide, like the guide for all of the IB experimental sciences, identifies “essential principles of the subject” that are common to both the SL and HL courses in a discipline, but the assessment statements used to define what should be taught are grouped by topic rather than thematically. Here also teachers are expected to organize and integrate the material on their own. While it is important not to specify course designs too rigidly, further guidance on organizing the recommended content might produce more consistent results—especially when teachers are undergoing changes in their practice.

In contrast, in the opinion of the mathematics panel, the topics in the AP calculus syllabi are appropriate and well connected. In its current formulation, AP calculus pays careful attention to the central concept of function and to connecting the common ways (numerical, graphical, analytical, and verbal) of representing functions. There is likewise careful attention to developing the main concepts of differentiation and integration, including several interpretations of and applications for each.

Examinations and Conceptual Learning

The AP and IB examinations could be improved if they required students to demonstrate a deeper level of conceptual understanding to earn passing grades. Two of the panels (calculus and chemistry) attribute this problem, of limited depth, at least for AP, in part to the relatively predictable nature of many items on the respective examinations. This characteristic allows or even encourages teachers to instruct students on how to answer particular types of questions, a practice that might not occur if tests consisted of widely varied items whose solutions required the integrated application of key principles.

For example, the mathematics panel is concerned that teachers may be encouraged to focus on teaching their students specific problem types instead of engaging them in modeling and problem-solving activities that would lead to greater understanding of the underlying concepts of the subject. As a result, students could compute a right answer in a limited range of situations but be unable to explain why their solution is correct. Students who do not understand the concepts underlying procedures will have difficulty using mathematics to solve unexpected problems or applying their knowledge in other disciplines, such as physics or economics, or in real-world settings.

The mathematics panel notes that the AP examination has improved under the new syllabus. The effort to promote conceptual understanding by asking nonstandard questions and requiring verbal explanations is an excellent step in the right direction. The fact that there is now a wider variety of applications of integration (and not from a prescribed list) encourages students to think about the meaning of an integral. The panel recognizes and applauds the fact that the College Board is taking such steps to encourage more modeling activities (applications) and to make its tests less predictable (see, for example, CEEB, 2001b). The mathematics panel notes that many problems on the IB mathematics examinations could also be solved procedurally if students were taught to do so or if they had solved enough practice problems. The panel concludes, however, that there is such a broad range of topics that it would be difficult for students to do well on the examination as a whole without understanding the underlying concepts. Indeed, the panel's analysis of the IB examinations suggests that considerable conceptual understanding is required for students to do well. It appears, however, that opportunities are missed throughout the exam to connect procedural knowledge with conceptual knowledge; this emphasis on procedural knowledge could lead to superficial instruction in IB classrooms.

The science panels call for final assessments that are better tests of conceptual understanding, with less emphasis on students' ability to remember discrete facts, formulas, and procedures. The inclusion of novel tasks that require the application of key principles could encourage teachers to focus on students' development of conceptual understanding and ability to make interdisciplinary connections. The use of a wider range of assessment strategies also might encourage effective instruction (Rice, Ryan, and Samson, 1998). The science panels note that both AP and IB are taking positive steps in this direction. For example, some AP science examinations ask students to design experiments and to demonstrate their solutions to problems. Doing well on this task requires that students have significant prior experience with designing experiments to solve a variety of problems. Teachers thus have an excellent incentive to engage students more regularly in these types of activities.

PRIOR KNOWLEDGE

Research on cognition has strongly confirmed the importance of prior knowledge for all aspects of thinking and learning. One reason prior knowledge is important is almost self-evident: new knowledge is built on what learners already know. Thus before entering AP or IB courses, students need a solid knowledge base.⁴ To focus the curriculum and instruction appropriately (a critical factor in maintaining student motivation, as well as in developing understanding), teachers need a clear idea of the depth of knowledge, skills, and experiences their students bring to the classroom.

Prerequisites

Both the AP and IB programs provide fairly detailed information about the necessary prerequisite knowledge and skills in mathematics.⁵ However, neither the College Board nor the IBO clearly specifies the competencies students must master in advance in the sciences. In both mathematics and the sciences, the College Board suggests (but does not require) that students complete a previous course or combination of courses before enrolling in AP sciences. Schools are free to adhere to these suggestions or not. Statements about the need for such courses are of limited value for several reasons. First, similarly titled courses vary widely in content and rigor, so students may not have the necessary background even if they follow this advice. Second, some students acquire the knowledge and skills necessary for success through independent study or related experience, not through traditional course taking. Finally, even when prerequisites are clearly specified, it may be difficult to ensure that students have met them.

The IBO does not specify any prerequisites for the experimental sciences. IB HL courses are taught over 2 years. Therefore, the IBO does not believe it necessary to specify prerequisite courses for the experimental sciences, assuming that a 2-year course of study provides ample opportunity for students to both build a solid foundation in the discipline and pursue advanced work. However, these courses also are built on prior knowledge to some extent, and this is worth specifying.

Identifying the prerequisite student knowledge and skills needed for success in each course is of considerable importance to schools in providing adequate preparatory experiences (tools for gauging student mastery of these skills would also be useful). A clear articulation of the body of necessary

⁴Interestingly, it has been shown that good science instruction in grades 1 and 2 can strongly influence learning throughout the high school years (Novak and Musonda, 1991; Sneider and Ohadi, 1998).

⁵The IBO calls these skills “presumed knowledge.”

prior knowledge could help teachers and counselors advise students about their readiness to take specific AP or IB courses, and appropriate assessments could help them identify areas of weakness that should be addressed before advanced study begins. The programs attempt to provide this information to varying degrees. However, identifying the full range of prerequisite content knowledge, conceptual understanding, and skills is a complex task requiring the combined efforts of experts from the science disciplines, cognitive psychologists, master teachers, and staff from the advanced study programs. The committee believes that the benefits for student learning are well worth the effort. At the same time, while this task is important, it is also essential that prerequisites not become barriers to participation for students from particular ethnic or socioeconomic groups (see Chapters 2 and 10, this volume).

An alternative to the use of more testing to measure readiness for advanced study might be to adopt a developmental approach, such as that devised by the Australian Council for Educational Research. Central to this approach are models of learning known as progress maps, which provide a sequential description of skills and knowledge indicating both the goal and the steps necessary to achieve it. Readiness for AP or IB courses could be calibrated with a position on such a map (as cited in NRC, 2001a, p. 181). Use of such an approach also might be beneficial for students seeking to prepare themselves for advanced work through independent study.⁶

The American Association for the Advancement of Science's (AAAS) Project 2061 program for science literacy recently produced an atlas of learning maps that indicate the interrelationships among science concepts. Although limited in scope at present, these maps provide a useful set of guidelines for building upon science concepts as students advance through school (AAAS, 2000). Adapting aspects of these maps could assist experts in developing appropriate measures of prior knowledge and readiness for advanced study.

Coordination of Courses

The fact that students need to acquire certain prerequisite knowledge and skills before participating in advanced study implies that greater attention should be paid to across-grade curricular and instructional planning. If advanced study is viewed as an extension of the regular curriculum, it follows that students' success in such programs depends on knowledge and skills acquired much earlier.

⁶To date, progress maps have been developed primarily for elementary and middle school mathematics and science. If they are to be useful for the purpose proposed here, teams of experts will be required for their development. Examples of progress maps can be found at www.acer.org/.

For example, the study of calculus logically builds on foundational knowledge acquired in previous courses in mathematics. Yet the mathematics panel points out that there are not enough checks in the system to ensure that students have mastered the algebra, trigonometry, and precalculus concepts and skills necessary for success in calculus and in courses beyond. The performance of many AP calculus students is undermined by the fact that they do not learn precalculus thoroughly, or learn adequately how to solve problems and think mathematically. This situation is not a defect of the AP calculus course per se, but of the system in which it is embedded.

An example of prior foundational knowledge is the periodicity of trigonometric functions, such as sine and cosine. While these are not calculus concepts, an understanding of these functions is needed in the study of calculus. If these ideas are learned poorly or not at all in previous coursework, the calculus teacher must devote valuable instructional time to their development, or some students will experience difficulty.

The science panels argue that a syllabus for a year-long advanced course that also serves as an introduction to the discipline allows too little time for students to develop the depth of conceptual understanding that should be the fundamental goal of advanced science courses. Thus they unanimously recommend that students study the biology, chemistry, or physics that is suggested for grades 9–12 in the *National Science Education Standards* (NRC, 1996) before enrolling in advanced high school courses in those disciplines.⁷ At the same time, to ensure that students who complete introductory courses do not face excessive redundancy in subsequent courses requires active coordination among teachers at different grade levels.

Implications of Prior Knowledge for Instruction

Because prior knowledge is so important to students' ability to understand new material, care must be taken to structure advanced courses around a coherent curriculum. That is, the presentation of topics must be sequenced so that the concepts and processes imparted to students gradually become more complex (AAAS, 2000). Neither the AP course descriptions (see for example, CEEB, 2001b, p. 8) nor the more detailed IB program guides provide guidance on sequencing concepts or topics. In fact, the IB Chemistry Guide notes that the order in which topics are presented on the course outlines does not constitute a recommended sequence: "It is up to the individual teachers to decide on an arrangement which suits their circumstances"

⁷All of the panels agree that there are exceptions to this general rule. For example, particularly precocious students or those who have had significant experiences outside of the classroom related to the discipline might be able to skip the first course.

(IBO, 2001b, p. 35).⁸ Similar statements are included in IB program guides for mathematics, biology, and physics (IBO, 2001a, p. 5; IBO, 2001c, p. 9). This flexibility can be a strength in the hands of good teachers because they can adjust their activities in response to what their students understand. On the other hand, less-experienced AP or IB teachers may try to follow college textbooks too closely, and according to the chemistry panel, their doing so could contribute to the problem of excessive breadth.

Misconceptions and Formative Assessment

One important subset of prior knowledge involves misconceptions and naive theories, as discussed in Chapter 6. Even well-performing students often retain and use deeply flawed prior beliefs. The AP and IB programs could address this problem in several ways. First, using emerging research on student misconceptions, they could include in their course guides information about typical misconceptions that students may already harbor or that may arise during study of each of the topics included in the courses. There is considerable research and detailed description of the common types of misconceptions held by learners in mathematics and physics (see for example, Driver, Squires, Rushworth and Wood-Robinson; 1994; Gabel, 1994; Minstrell, 2000b). Information might be provided in the teachers' guides about these common misconceptions, as well as strategies that could be used to address them. Second, a focus on detecting and addressing common misconceptions in content areas could be built into professional development programs. Third, items could be included in the AP and IB final assessments that would reveal common misconceptions, thus focusing teachers on the goal of identifying and remediating misconceptions that persist even after instruction. While the AP physics examination now does this to some extent, the mathematics panel notes that AP calculus examinations miss opportunities to include questions that address common student misconceptions, such as those that arise in attempting to understand the derivative, slope fields, and functions.

One effective strategy for identifying student misconceptions, especially those that endure after instruction, is the use of curriculum-embedded (formative) assessment, which enables teachers and students to set intermediate goals for learning and to select appropriate materials and tasks for pursuing those goals. Formative assessment can also provide information about students' preconceptions and misconceptions, thereby informing subsequent instructional choices (see, for example, Kozma and Russell, 1997; Mestre, 1994; Minstrell, 2000a; NRC, 2001a). The College Board and the IBO could

⁸Similar statements are found in AP course guides and teacher's guides.

develop or help teachers develop the tools needed for this purpose. Although some excellent teachers apply this strategy already, it probably cannot be presumed that most do so.

The IBO helps teachers integrate formative assessments of students' practical (laboratory) work and portfolios into instruction on an ongoing basis. However, it does not provide guidance on the development or structure of other forms of ongoing assessment. The AP program provides no explicit guidance on the structure or development of classroom-based assessments, although course guides and teachers' guides mention the usefulness of such measures. The panel's appraisal of professional development materials provided by the AP and IB programs indicates that classroom assessment receives limited attention.

Lacking appropriate interim assessments, many teachers use previously released final examination questions throughout the school year to measure student achievement. This strategy may be useful for predicting students' performance on the AP or IB examinations or providing practice with the test format and item types, but it is of little use as a tool for identifying misconceptions or appraising students' conceptual understanding because the test items are not designed for this purpose. AP and IB teachers also would benefit from professional development opportunities directed toward improving their knowledge of common misconceptions and assisting them with the development of activities or formative assessments that could be used to detect and address those misconceptions. Experienced teachers of advanced study would be needed to staff such workshops.

METACOGNITION

Advanced study courses present a significant opportunity for providing students with instruction in metacognition, or self-monitoring of learning (Mintzes, Wandersee, and Novak, 2000). Research has shown that strong metacognitive skills are characteristic of experts in any field, as well as of effective school-age learners, and that they are developed most effectively in the context of a discipline. For example, White and Frederickson (1998) demonstrate that teaching students metacognitive strategies in physics improves their understandings of the concepts of that discipline. Similarly, Schoenfeld (1983, 1984, 1991) shows that a metacognitive approach to instruction improves students' heuristic methods for mathematical problem solving.

Minimally, AP and IB course materials should recognize proficiency in metacognition as a goal of advanced study. Teachers should elicit metacognitive activity in classroom discourse by posing questions and modeling reasoning. In addition, suitable opportunities for students to demon-

strate metacognitive strategies should be built into curricular materials and assessments. The goal should be to help students become proficient in monitoring their own thinking and learning.

Although the AP course outlines and professional development programs for mathematics and science teachers currently pay little explicit attention to metacognition, the teachers' guides suggest that teachers help students develop skills that are important components of metacognitive strategies. For example, according to the teacher's guide for AP chemistry (Mullins, 1994, p. 8), "It would be unreasonable to expect that all AP students come into the class with strong analytical and critical thinking skills; therefore the AP teacher must strive to strengthen these skills within the students. A process of problem solving should be continually modeled and reinforced." Likewise, the teacher's guide for AP calculus (Kennedy, 1997, p. 48) suggests that "teacher modeling of questioning and exploration, multiple approaches to problem solving, correct use of terminology, clarity of work, and openness to the ideas of others are all essential." The committee views these suggestions as positive steps toward addressing the important role of metacognition. However, the statements in the teacher's guides are isolated, and the committee believes the importance of metacognition currently is substantially underrepresented in both the teacher's guides and the types of questions students encounter on the final AP examinations in science. As is the case for principled conceptual knowledge, an instructional emphasis on metacognition will not be realized until that emphasis is reflected in the assessments.

The committee views as promising the fact that in future AP calculus examinations, students will be required to justify and explain their solutions to all calculator problems. Scoring rubrics will consider both the correctness of the solution and whether the reasons for using the selected procedures are justified. Given the strong influence of the assessments on the content and structure of curriculum and instruction, it is likely that AP calculus teachers will provide frequent opportunities for students to make their thinking visible. The committee commends the AP calculus development committee for its attention to this important principle of learning and encourages other AP development committees to follow suit.

The IB program also provides significant opportunities for students to learn and develop metacognitive skills. As discussed in Chapter 4, the IB Theory of Knowledge course⁹ is designed to provide students with knowledge about cognitive processes and strategies, practice in using those strategies, and opportunities to evaluate the outcomes of their efforts. "It encour-

⁹This course is a requirement for students seeking an IB Diploma (see Chapter 4, this volume, for other requirements).

ages students to become aware of themselves as thinkers, to become aware of the complexity of knowledge, and to recognize the need to act responsibly in an increasingly interconnected world” (IBO, 2000b, p. 3).

DIFFERENCES AMONG LEARNERS

The existence of differences among learners and the extraordinary complexity of such differences have implications for how educational programs are structured, how students are taught, and how learning is assessed. They are also relevant to teacher professional development.

Research on how students differ in knowledge representation and expression is difficult work that is not yet complete. Nonetheless, programs such as AP and IB can begin to address student variations by building corresponding variability into their curricula and assessments and by addressing learner differences as part of their professional development opportunities for teachers. While variety will not ensure a perfect match of instruction or curriculum to the preferences or abilities of each student, it will likely provide many more students with opportunities to learn in ways best suited to their strengths, at least some of the time.

AP or IB teachers who creatively mix pedagogical approaches with sensitivity to the profile of learners in particular classes are likely to reach a broad range of students with varying learning modes and may motivate more students as well. The IB program guides for the experimental sciences recognize the importance of this tenet by indicating that there is no single best approach to teaching IB courses and that teachers should provide a variety of ways of acquiring information that can be accepted or rejected by each student, allowing different routes through the material (IBO, 2001a, 2001b, 2001c, p. 11). A combination of approaches is also likely to result in students learning the same concepts in multiple ways, a strategy that is conducive to building deep understanding. An example of such a strategy is the current “rule of four” emphasis in calculus, which suggests that students, with the help of their teachers, see the links among four representations of mathematics: numerical, graphical, symbolic, and verbal.

Using Differences Among Learners in Assessment

As discussed in Chapter 6, students with different learning styles may need different ways to demonstrate their knowledge and skills. For example, some students work well under pressure, while the performance of others is significantly diminished by time constraints. Some students express themselves well in writing, while others do not. Using one form of assessment will work to the advantage of some students and to the disad-

vantage of others. Research (see, for example, Linn, 2000; Mintzes et al., 2000; NRC, 2001a) also indicates that the use of different measures administered over a period of time will offer a more accurate picture of what students know than any single measure can provide (Linn and Hsi, 1999). Using information gathered from multiple sources shows respect for the diversity among learners.

The internal assessment that is part of all of the IB experimental science courses and the portfolio that is part of the IB mathematics courses are examples of how large-scale assessment can incorporate the results of different types of measures into a final evaluation of student achievement. However, the scores earned on the internal assessment and the portfolio are not reported separately, but are combined with scores earned on the written final examination and contribute only a fraction of the student's total score. Therefore, some information is lost that might be useful in providing a fuller picture of students' capabilities.

The AP reporting levels of 1 to 5 do not differentiate well among students at higher levels of achievement. A score of 5 putatively represents a commendable level of proficiency, but it fails to capture just how proficient a student is or what a student knows qualitatively. At all levels of achievement on the AP assessments, the score by itself does not speak to what students actually understand. For example, a student who earns a 3 on an AP biology examination might know a great deal about a few topics or less about many things. A student who earns a score of 1 might either know little or have failed to make an effort on the examination. The physics panel addresses this issue at length, indicating that two students who earn scores of 5 can have vastly different levels of understanding. Scores on the 2000 AP Physics B examination that result in a 5 range from 104 to 180. The panel states unequivocally that students at the higher end of the score range are far more competent than those at the lower end. Institutions receiving student scores could benefit from information that reflects this difference. The committee notes that even students who achieve a score of 5 could have serious gaps or inconsistencies in their understanding, and these gaps ought to be revealed as well.

With some planning and effort, the College Board could do much better in assigning qualitative meaning to summary scores.¹⁰ One possibility is that a numerical summary of performance—say a score of 4—could be linked to a description of what students who earn that score are likely to understand.

¹⁰The committee notes that the reporting structure of an assessment cannot be modified without considering whether the test can support the inferences that will be drawn from the reported scores. If they cannot, changes may have to be made in the test itself. This requires long-range planning and changes that must be made at the test development stage.

It also may be possible to review the specific responses of examinees and evaluate them for gaps in understanding, or to provide subscores for specific skill and knowledge areas. Currently, most AP examinations do not include enough items targeting the same concept or skill to allow development of a meaningful subscore for individuals.¹¹ An exception is the AP Calculus BC exam, which already provides a useful subscore indicating proficiency on the AB section of the material. To develop useful subscores on other exams, the assessments might have to cover less material more deeply or include more items. Reducing the breadth of material covered on the assessments could potentially accomplish two important goals: providing more meaningful and useful information about student performance, and reducing the breadth of content teachers are expected to cover and students are expected to learn in AP classes.

MOTIVATION

Learners' academic motivation influences their choices about which tasks to undertake, the persistence with which they pursue these tasks, the level of effort they expend, and their thoughts about the usefulness of the tasks and their performance on them. Eccles and colleagues (Eccles, Wigfield, and Schiefele, 1998) organized research about motivation into three broad questions students might ask themselves when confronted with a new task: Can I do this task? Do I want to do this task and why? What do I have to do to succeed on this task? These questions are used below to frame an analysis of the ways in which the AP and IB programs help or impede students in developing and maintaining their motivation in advanced study programs.

Believing in the Possibility of Success

Factors that contribute to students' sense that they can be successful in AP or IB courses have been discussed earlier in this report. These factors include students' positive beliefs about their own competence, their expectations for success or failure, their sense of control over the outcomes, their belief that others think they are competent, their belief that support of various kinds is available if they need it, and a strong sense that what they have learned before is adequate preparation for the challenges they will face in AP or IB. The IBO's Middle Years Programme and the College Board's Vertical Teams, Equity 2000, and Pathways Programs are designed to help students believe they can be successful in AP and IB courses.

¹¹Currently the College Board provides aggregate subscore information to teachers of classes in which five or more students sit for the examination. The IBO provides similar feedback to its teachers.

Deciding to Enroll in an Advanced Course

Many able high school students and others take AP and IB courses because they seek opportunities to challenge themselves academically—opportunities that might otherwise not be available in high school courses. Others select these courses because they believe extrinsic rewards will accrue to them for doing so. These rewards include, for example, a potential advantage in the college admission process at competitive colleges,¹² opportunities for academic recognition, the possibility of earning college credit, and the possibility of placing out of introductory college courses.¹³ Most students, however, are motivated by a combination of internal and external factors.

Some students take these courses because their parents want them to do so. Parents' reasons may include those mentioned above, as well as beliefs that AP and IB courses are taught by better teachers and produce more learning, that there are fewer discipline problems in these courses, and that students will have greater access to resources and opportunities in these courses than in others. Peers also exert a strong influence on students' decisions on whether to enroll. Students who are members of peer groups that value AP or IB participation are probably more likely to enroll even when they are not personally interested in a course. This observation may have serious implications for able students who attend schools where their peers do not value academic achievement. Still others take AP and IB classes because no other options exist in their high schools. This is particularly the case in mathematics: students who complete precalculus often have no other choice but to take AP or IB calculus if they want to continue with mathematics.¹⁴

Investing Effort for Success

Even when students are prepared to take AP or IB courses and have determined that they want to do so, they still must ask themselves whether

¹²Responses to a survey of college admission officers conducted by the committee clearly indicate that student perceptions in this area are accurate and that the more selective a college is in terms of admission, the more important it is that a student participate in AP and IB courses if their high school offers such courses (see Chapter 2, this volume).

¹³The committee conducted a survey of biology and mathematics departments at a sample of colleges and universities to ascertain how AP test scores are used for placement and credit (see Chapter 2, this volume).

¹⁴In September 1986, the Mathematical Association of America and the National Council of Teachers of Mathematics released a joint statement advocating that calculus courses taken in high school be at the college level, in other words, at the level of AP or IB. The statement was published in *Calculus for a New Century* (Steen, 1988).

they are willing to expend the effort required for success. Researchers have begun to examine the relationships among motivation, cognition, and the social context in which learning takes place. The results of some of this work suggest that educational programs designed in accordance with the principles of learning described in this report can enhance students' motivation to engage in advanced study even when considerable effort is involved. Research also has shown that when computers, teachers, and peers are integrated as learning partners, not only does greater achievement result, but also more positive affective changes occur (Canas, Ford, Novak, Hayes, and Reichherzer, 2001; Linn and Hsi, 1999).

Motivation and the Final Examination

It is interesting to note that a far larger percentage of IB than AP students take the final examinations.¹⁵ The IBO promotes the idea that IB courses prepare students for success in college and in real life. The examinations, students are told, are an integral part of the course and are the best way for them to demonstrate to themselves and others that they have achieved competence. In contrast, AP materials focus primarily on the usefulness of AP test scores for college credit and placement. If students lose interest in earning credit or placement or the colleges at which they plan to matriculate do not accept AP credits,¹⁶ they may choose not to sit for the examinations.

The College Board is concerned about the number of students who do not take the AP examinations and is considering ways to address this issue (CFAPP, 2001). All four of the panels and the committee believe that sitting for the examinations should become an integral part of AP courses (see Chapter 11). Otherwise, students will miss an important opportunity to validate their performance, colleges and universities will lack information that can be highly useful in deciding on appropriate placements, and AP will be less credible as a rigorous program for high school students.

LEARNING COMMUNITIES

Learning is mediated by the social environment in which students interact with others. Although students also learn individually, research indicates

¹⁵Virtually all IB students take the examinations (Campbell, 2000). In contrast, only two-thirds of AP students sit for the examinations. (This is an overall estimate provided by the CFAPP [2001], but the committee does not know the extent to which this figure varies across disciplines. It may be, for example, that almost everyone who takes AP U.S. history sits for the examination, but only 25 percent of AP chemistry students do so, or vice versa.)

¹⁶Students generally receive acceptance to college prior to the May AP examination dates.

that learners benefit from opportunities to articulate their ideas to others and listen to and challenge each other's ideas, and in so doing reconstruct their thinking. Teamwork and collaborative investigations similar to those in which professional scientists engage help students refine important concepts and principles and apply them in real-world contexts. Students build on the learning of others through interaction. For example, students who are using an ineffective problem-solving strategy can learn by observing others who are using more productive methods.

The panels see learning communities as an important avenue for students to develop advanced understanding in their disciplines. The panels recognize the importance of discourse to both student construction of understanding and scientific discovery (Dunbar, 1995). They are concerned, however, that the push to cover too much content during the course of a school year can discourage teachers from permitting students to engage in lengthy discussions, ask questions, make conjectures, and challenge each others' ideas. The science panels' reviews of the broad scope of AP and IB course outlines, sample course syllabi, school scheduling options, and their own experiences lead them to believe that in many (but not all) AP and IB science classrooms, a lecture format is used extensively. Lectures can be an efficient tool for transmitting information, but they are not very useful for eliciting students' misconceptions, helping them understand the conditions for which principles are valid, or providing them with opportunities to practice skills and receive feedback. Traditional lecture formats limit the ability of students to be active participants in their own learning because they cannot control the pace of the information that is being presented, and interaction between lecturer and learner is limited at best.

The science panels are also concerned that students' opportunities to engage in collaborative work with peers in the laboratory components of science courses may be limited by the brevity of the periods within which the laboratories must be offered in today's high schools. They note that most college students engaged in the same courses have laboratory periods that are 2 to 3 hours long. The panels commend the College Board for advocating longer laboratory periods (CEEB, 2001a, 2001c, 2001d), but are skeptical about the frequency with which schools are able to implement this suggestion because of other scheduling constraints. The science panels note that a reduction in the breadth of science curricula could allow more time for collaboration and inquiry.

The panels note approvingly that the internal assessment criteria for IB experimental science courses require teachers to structure the classroom and laboratory environments so that students have opportunities to acquire and develop skills in working with a team. It is likely that both the AP and IB programs could make more deliberate use of interactions in promoting students' understanding of science and mathematics through such strategies as

group case studies, project-based science activities, and use of technology that facilitates discourse (Ryder, Leach, and Driver, 1999). Finally, it may be noted that although class time is limited, collaboration can be encouraged outside of class on homework and other assignments, at the discretion of the teacher.

LEARNING IN CONTEXT

The situative perspective recognizes that learning occurs best in the context of performing problem-oriented tasks analogous to those encountered in real work environments. Active, inquiry-based learning should therefore be a major component of the learning environment.

There are many instructional techniques teachers can use to situate learning, such as case-based or problem-based instruction and simulations. However, as mentioned in Chapter 6, care must be taken with all of these approaches to provide multiple opportunities for students to engage in activities in which the same concept is at work; otherwise learning could become overly contextualized, and students might not be able to discern its usefulness in solving different types of problems. The IB program recognizes this: “Students need to be exposed repeatedly to the application of basic concepts to new situations. This can be done through examples used in the classroom, by homework assignments which provide a variety of appropriate situations requiring skills beyond recall of information, and by tests and examinations which use questions similar to those used in the IB examination” (IBO, 1999a, p. 401). There are two primary reasons, however, why multicontext learning is unlikely to occur in AP and IB classrooms: there is a great deal of material to cover in preparation for the examinations, and the AP and IB assessments do not measure students’ understanding of underlying principles in unfamiliar contexts frequently enough.

In the real world, problems are not organized neatly into discipline-specific packages. Thus from the situative perspective, advanced study teachers should provide opportunities for students to explore the interdisciplinary connections relevant to complex tasks. Doing so not only makes learning more interesting and motivating, but also develops students’ capacity to generalize their learning. In this regard, the mathematics panel concludes:

The AP program does not make a sufficient attempt to connect calculus with other fields in a realistic way. There is a tendency to use applications of rather ritualistic and formulaic kinds, and of limited difficulty. The test concentrates on a few prescribed applications (e.g., determination of volumes) or gives applications that consist largely of interpretation of symbols or computations in a new context. Its problems have a “whiff” of application, but they are often jarringly unreal at a deeper level.¹⁷

¹⁷See the panel’s report at www.nap.edu/catalog/10129.html.

While the IB external assessment lacks realistic connections to other disciplines, the IB portfolio, which was added to the mathematics program in 2000, includes a modeling exercise that emphasizes interdisciplinary connections with science. The committee and the mathematics panel applaud this new emphasis and encourage the IBO to expand this emphasis to the external assessment. The IB science courses include interdisciplinary topics in some of the topic options and in the required Group 4 interdisciplinary project (see Chapter 4, this volume, for more information about the IB Group 4 Project). In addition, the selection of curricular options in IB experimental science courses is based on resources that are available locally. For example, an IB chemistry curriculum in a school with access to a university's analytical laboratory might include higher physical organic chemistry or modern analytical chemistry. Similarly, a curriculum in a school located in an area where there are chemical manufacturing plants could include the Chemical Industries option. Thus students develop knowledge that is situated in the relationships, practices, and tools of a community. The AP science curricula do not encourage links to other science disciplines, probably as a result of the independent development of each AP course.

The laboratory components of AP and IB science courses can provide excellent opportunities for teachers to situate learning in activities that reflect the kinds of thinking and problem solving in which scientists engage. The physics panel notes that experimental work in advanced courses should provide experience with the ways scientists use experiments, both for gathering data to build theoretical models and for exploring the applicability of these models to new situations. Although both the AP and IB programs emphasize the central role laboratory experiences should play in students' learning, the science panels note that the potential for helping students learn how science is conducted is not realized to an optimal extent in either program. For example, the biology panel notes that the AP required biology laboratories tend to be more "cookbook" (i.e., a set of prescribed procedures) than inquiry-based and consequently do not replicate the ways scientists work. The physics panel is similarly concerned about the "cookbook" nature of many physics laboratories commonly used in schools. In these laboratories, students do not have adequate opportunities to make the kinds of decisions scientists make from the conception of an experiment to the critical review of its results.

Another aspect of situated cognition as related to laboratory work is the ability to use instrumentation. The science panels note that skilled use of instrumentation is an important aspect of the context in which scientific discovery occurs. Through the use of authentic activities, including laboratory work and the skilled use of appropriate instrumentation, the situated nature of learning is respected. Students are less likely to memorize words or phrases that hold no meaning except for helping them obtain high exam

scores or grades. Instead, learning can be embedded in more authentic contexts and realistic activities, using tools appropriate to the subject. The biology panel notes that the AP biology laboratory exercises do not require much instrumentation. The physics panel indicates that neither AP nor IB curricula reflect the growing use of computer modeling for the study of physics.

IB science and mathematics assessments, as a function of the internal assessment¹⁸ and portfolio¹⁹ components, respect the situated nature of learning better than do AP assessments.²⁰ This is because the AP examinations rely exclusively on a single assessment that uses only multiple-choice and free-response questions to measure student achievement. The chemistry panel contends that paper-and-pencil assessments, such as the AP examinations, are not sufficient to measure students' understanding of laboratory methods or interpretation of laboratory data. The biology and physics panels concur. The mathematics panel, while appreciative of the portfolio component of the IB mathematics courses, does not believe the portfolio alone eliminates the need to include on the final examinations questions that require students to use their knowledge and skills to solve real and unfamiliar problems.

CONCLUDING REMARKS

This chapter has presented an analysis of programs for advanced study through the lens of research on learning, as summarized in Chapter 6. The focus has been on the themes of conceptual learning, prior knowledge, differences among learners, motivation, learning communities, and the context of learning. In general, although the programs have important strengths, they do not yet effectively utilize what is known about how people learn. In many instances, they insufficiently emphasize conceptual learning that uses inquiry-based methods, nor do they adequately take into account the importance of prior knowledge (including student preparation in earlier courses). Some of the courses are too broad to allow mastery. Most could do more to help students gain the ability to apply their learning in unfamiliar situations.

¹⁸The internal assessments in the experimental sciences are focused on the candidates' skills in laboratory investigation, which include planning, data collection and processing, evaluation of procedures and results, and manipulative skills and personal skills, which include working with a team (IBO, 2001a, 2001b, 2001c, pp. 20–22).

¹⁹The purpose of the mathematics portfolio is to “provide candidates with opportunities to be rewarded for mathematics carried out under ordinary conditions, that is, without the time limitations and stress associated with written examinations” (IBO, 1998b, p. 47).

²⁰As discussed in Chapter 4, the IB internal assessment allows teachers to evaluate students as they use their knowledge and skills to solve real problems in settings other than testing.

Although the analysis here has included examples from the four disciplines on which this study is focused, the discussion has been fairly general. Readers who are interested in one of the disciplines in particular will find an in-depth assessment in the corresponding panel report. Readers are encouraged to peruse these reports individually or to examine the summary of their findings presented in Appendix A.

Chapter 9 examines the AP and IB programs from a different but related point of view: the four elements of educational programs—curriculum, instructional methods, ongoing and end-of-course assessments, and opportunities for teacher preparation and professional development. The discussion in that chapter considers the extent to which these elements of the AP and IB programs nurture deep conceptual understanding among students—the committee’s view of the primary goal for advanced study.

Analysis of AP and IB Curriculum, Instruction, Assessment, and Professional Development

This chapter reviews the AP and IB curricula and associated instructional strategies, assessments, and professional development opportunities to identify those features that are consistent with the design principles set forth in Chapter 7. Also examined are the ways in which the four program elements interact to support or undermine students' attainment of the deep conceptual understanding that is the goal of advanced study. In presenting this analysis, the committee acknowledges that there are many teachers in the United States who, by virtue of their experience and pedagogical skills, are able to overcome many of the program deficiencies discussed. We also recognize, however, that an improved program would only serve to enhance the capabilities of these teachers. Additionally, for the many teachers who are not as skilled or experienced, it is important that the curricula and related assessments and teacher preparation for these courses be aligned more completely with what is known about learning to ensure high standards and quality instruction for all AP and IB students.

CURRICULUM

Depth Versus Breadth

The committee's analysis of the AP and IB programs reveals some fundamental characteristics that are incompatible with a curriculum designed to foster deep conceptual understanding. The first major discrepancy, which applies equally to AP and IB, relates to the "less is more" concept in curriculum design. The idea is simple: only if a curriculum is not overly broad in terms of the number of topics to be studied is it possible to study topics in

sufficient depth to develop deep conceptual understanding. This idea is consistent with national standards in mathematics and science for grades K–12 (American Association for the Advancement of Science [AAAS], 1993; National Council of Teachers of Mathematics [NCTM], 2000; National Research Council [NRC], 1996). While the written materials produced by the College Board and the International Baccalaureate Organisation (IBO) acknowledge the importance of depth and focus, the daunting scope of the curriculum guides and the associated assessments in some subject areas sends a very different message. One notable exception is the revised AP calculus syllabus, which reflects an appropriate balance between breadth and depth.

Curriculum Development

AP course outlines (and assessments) are designed to mirror the content of typical college-level introductory courses (see Chapter 3, this volume). AP courses are intended to be an acceptable substitute for the introductory courses offered at more than 2,000 colleges and universities. Because AP courses cannot duplicate all of these college offerings, AP development committees try to make the courses maximally similar to as many of their college counterparts as possible. If one makes the commonsense assumption that college-level courses vary substantially in quality, such an approach will limit the development of high-quality AP courses. *Average* and *excellent* are incompatible. By focusing on average rather than exemplary programs, the development process results in an almost certain regression to the mean. A far better goal for the development of AP courses would be to design them in accordance with the principles articulated in this report. Further, suggested instructional strategies should reflect the range of best practices in both high school and college courses instead of emulating college courses across a range of quality and content. Throughout the development process, the goal of fostering learning with deep conceptual understanding must always be pursued.

AP course content is determined using data supplied by college and university department officials who respond to a survey distributed by the College Board. According to College Board officials, the response rate to these surveys is rather low—approximately 40 percent. Thus the responses of a small number of college and university departments may have an undue influence on what is taught in advanced courses across the nation. Designing AP courses to reflect a typical college course also means that until curricular changes become common in introductory college courses, these changes will not be included in AP. On the other hand, because IB courses are developed differently (see Chapter 4, this volume), they can be more responsive than AP courses to changes in the disciplines.

The committee notes that in the 1990s, the College Board began experimenting with other development strategies. In 1994, 23 nationally recognized experts in the area of calculus reform were brought together to work with the development committee in redesigning the AP calculus curriculum. The give and take and varying perspectives of these experts helped create a course that did not simply replicate a typical college course, but reflected current consensus on best practices in mathematics teaching and curriculum design.¹ The collaborative model used to develop AP calculus offers insight into how course development procedures could be modified to improve programs. The best possible outcome is that a focus on quality will result in university and AP courses having reciprocal effects on one another.

Variability

As noted earlier in this volume (see Chapters 3, 4, and 8), AP and IB courses in the same discipline vary from school to school and even from classroom to classroom. Individual teachers are given substantial leeway in implementing AP or IB courses in their classrooms. While flexibility in curricula is an attractive feature for many experienced teachers, allowing them to be creative in their instructional approaches, the result is that college and university faculty face the same problems as AP and IB teachers in being unable to determine what incoming students know and are able to do.

Research on the nature and effectiveness of various practices in AP and IB classrooms is scant. Little is known, except anecdotally, about how AP and IB classrooms are organized, how the courses are implemented, and how they relate to existing school and district curricular offerings. School differences also affect how a course is implemented. The length of class periods, available facilities, and existing state standards, for example, all help shape the courses differently in each locality. Research is needed to understand these differences and their effects on student learning and achievement.

INSTRUCTION

Both the AP and IB programs depart significantly from the committee's framework for designing effective programs for advanced study by failing to address the element of instruction adequately. Neither the College Board nor the IBO gives sufficient attention to identifying and modeling aspects of

¹For a complete history of the reform of AP calculus, see <http://apcentral.collegeboard.com/article/0,1281,150-155-0-8019,00.html> (February 2, 2001).

instruction that foster learning with understanding. Further, neither program presents explicit models of the nature and range of excellent teaching in AP or IB classrooms. Sample syllabi, Internet discussion groups, professional development activities, and other resources provided by the College Board and the IBO are of varying quality, represent limited perspectives on excellent instruction, and do not adequately take into account variability among students and schools.

Because both AP and IB courses are designed to prepare students for external, standardized final examinations, instruction in AP and IB classrooms is typically directed toward that goal. Unfortunately, the broad scope of the AP and IB curricula, the significant number of examination questions that appear to require only rote learning, and the predictability of the questions included on some examinations may lead teachers to focus their attention on presenting information and teaching problem types, rather than facilitating active student involvement in learning.

Worthwhile Tasks

One of the primary responsibilities and challenges facing teachers of AP and IB courses is the selection and development of worthwhile problems, exercises, tasks, projects, and investigations that can simultaneously develop conceptual understanding, prepare students for successful performance on the examination, and address the varying abilities and preferences of students in the classroom. Currently, AP and IB materials provide little assistance for meeting this challenge.

Promotion of High-Quality Instruction

High-quality instruction in AP and IB science and mathematics courses depends on the availability of qualified teachers. The committee found that neither the College Board nor the IBO has clearly defined the preparation and qualifications of AP or IB teachers; doing so could contribute significantly to the quality of instruction in the programs.

Schools and districts also have an important role to play in promoting high-quality instruction in AP and IB classrooms; the College Board and the IBO cannot do it alone. High-quality instruction depends on many things, such as adequate instructional resources and laboratory facilities; a structure that allows enough time for instruction; ongoing availability of high-quality professional development opportunities; and support from administrators, parents, and educational policymakers.

Most important, schools and districts must recognize that effective teaching in AP and IB classrooms requires time. Advanced study teachers, like other

effective teachers, need time to remain abreast of changes in their subject areas and in the pedagogy related to their disciplines. AP and IB teachers need time to prepare their classes, carefully grade and comment on student work, and engage in collaboration and lesson planning with other teachers (see Chapter 2, this volume). For example, Ma (1999) indicates that teachers in China spend more time preparing lessons than teaching them. Time for collaborative planning is an important part of teachers' school hours in China. In the United States, teachers average approximately 13 minutes of planning time for every instructional hour (Darling-Hammond, 1999b; National Commission on Teaching and America's Future, 1996).

ASSESSMENT

AP and IB courses are designed to prepare students for standardized final examinations. Teachers select curriculum materials and gear instruction to prepare their students for success on these examinations, and students focus their learning on the concepts and content they believe they will encounter on the assessments. It is important, therefore, to better understand whether these assessments are aligned or in conflict with the principles of learning with understanding and the design principles of assessment.

Examination Design and Development

As noted earlier (see Chapter 3, this volume), AP examinations are designed by development committees for each of the disciplines in consultation with statisticians and psychometricians to create examinations that meet accepted standards for technical quality (American Educational Research Association [AERA]/American Psychological Association [APA]/National Council on Measurement in Education [NCME], 1999).² Thus, the development process incorporates the judgments of both disciplinary and psychometric experts. IB examinations are designed differently, in a manner similar to that which might be used by teachers who have a sophisticated understanding of their discipline (see Chapter 4, this volume). Thus, the development of IBO assessments depends heavily on the expertise and professional judgment of master teachers and less on psychometric calibrations. These differences between the two programs' assessments should be considered in light of the ways students' examination scores will be used and the kinds of inferences users expect to support with the scores.

²Readers who are interested in a more detailed discussion of test construction are referred to other sources (see, for example, AERA/APA/NCME, 1999; Millman and Greene, 1989).

Support for Inferences Drawn from Assessment Results

As noted in Chapter 6, validity research is a vital component of any high-quality assessment program. Validity involves what an examination measures and the meaning that can be drawn from the scores and the actions that follow (AERA/APA/NCME, 1999; Cronbach, 1971). For each purpose for which the scores are used, there must be evidence to support the inferences drawn. In the case of AP, for example, the College Board wants users to draw the inference that students' performance on AP examinations is indicative of their mastery of material taught in a typical college course in the subject. The IBO wants users to draw the inference that students who earn an IB Diploma through their performance on six IB examinations³ are adequately prepared for postsecondary work in many countries.

"The process of validation involves accumulating evidence to provide a sound scientific basis for the proposed score interpretations" (AERA/APA/NCME, 1999, p. 9). The AP Technical Manual describes two common interpretations of AP scores: (1) a good AP grade indicates that the student would benefit from entering a course more advanced than the usual first-year course, and (2) an AP grade indicates that the student should receive credit for a college course that he or she has not taken.⁴ The IBO does not describe the appropriate interpretations of IB grades other than to say that they reflect students' mastery of course content that is designed to prepare them for postsecondary learning.

Given these desired interpretations, validation studies for the AP and IB assessments should include systematic evaluation of such factors as whether the right skills and knowledge are being measured and in the right balance; whether the cognitive processes required by the test are representative of the ways knowledge is used in the discipline; the extent to which the test measures students' knowledge of the broader construct that is the target of instruction, as opposed to their knowledge of specific test items; whether the scoring guidelines focus on student understanding; and whether the test scores accurately represent different levels and kinds of understanding.

The committee's analyses of the test items and the course syllabi on which the tests are based yielded information about content coverage. However, no data were available for evaluating whether the tests measure important cognitive skills. This is because neither program has systematically gathered data to document that test items on its examinations measure the skills they purport to measure. In making determinations about the validity of

³There are additional requirements for an IB Diploma (see Chapter 4, this volume).

⁴See www.collegeboard.org/ap/techman/chap5/ (November 28, 2001).

inferences, it is necessary to know, for example, that test items intended to measure problem solving do in fact tap those skills and do not just elicit memorized solutions or procedures. There are a number of ways to collect such data. For example, cognitive laboratories might be conducted during which examinees would “think aloud” as they responded to test questions. Information from such laboratories gives test developers insight into the thought processes used by students to derive answers to test questions.

Validity evaluation should consist of more than a haphazard set of research studies. A sound validity evaluation should integrate “various strands of evidence into a coherent account of the degree to which existing evidence and theory support the intended interpretations of test scores for specific uses” (AERA/APA/NCME, 1999, p. 17). Yet the committee’s analysis indicates a surprising lack of information about what the AP and IB assessments actually measure. To date, neither program has implemented a strong program of validity research. The committee found only a few validity studies conducted with AP or IB data. For example, Morgan and Ramist (1998) examine college course-taking patterns for AP students; Morgan and Maneckshana (2000) compare performance in advanced-level courses for AP and non-AP students; and Eugene Carson reports on a small study at Virginia Polytechnic Institute and State University that compared the overall grade point averages of IB students with those of AP students and students who participated in neither program.⁵ While these studies may be useful, they do not represent pieces of an integrated research program (see Chapter 10, this volume, for a discussion of these studies).

Consequential Validity of AP and IB Assessments

Very little evidence is available for evaluating the consequential validity⁶ of the AP and IB assessments. With regard to this aspect of validity, relevant questions might include whether typical examinees become more or less interested in the domain as a result of their experience and whether they are more or less likely to pursue further study than those who do not sit for the examination. In the context of this report, one might ask how students who participate in AP and IB fare in college relative to other students and what the effect is on colleges of the ever-increasing numbers of students entering postsecondary institutions with college credit earned on AP or IB examinations. Equity concerns should also be considered, that is, whether the assessment unintentionally produces inequities of achievement or attitude in either the short or long term. While Morgan and Ramist (1998) begin to

⁵Available at <http://www.rvcschools.org> [August 2000].

⁶Consequential validity refers to the consequences or uses of assessment results.

address some of these questions, additional studies are needed. Information about the consequential effects of AP and IB assessments are especially important as these programs expand and become a more significant component of U.S. education.

PROFESSIONAL DEVELOPMENT

A common theme of the four panel reports that also emerged throughout the committee's deliberations is the crucial importance of professional development for enhancing teachers' content knowledge in their subject areas. As noted in Chapter 7, this volume, a strong grounding in subject matter knowledge is fundamental to good teaching and should be a primary goal of professional development activities. It is unrealistic to ask teachers to cultivate a deep, principle-based understanding among their students unless they themselves have such understanding. However, the ideal role of professional development for advanced study goes far beyond ensuring that teachers know their subject areas well. Effective professional development also enhances teachers' subject-specific pedagogical knowledge and provides them with multiple perspectives on students as learners. It is grounded in situations of practice; takes place in professional communities; actively involves teachers; and is an ongoing, long-term component of their professional lives. The committee believes that without well-designed and ongoing professional development, it is difficult for teachers to provide high-quality instruction that is aligned with curriculum and assessment to support the goal of learning with understanding. The committee notes that neither AP nor IB professional development opportunities are sustained and that teacher participation in both programs is voluntary.

The mathematics and science panels note that the summer programs offered by AP are highly variable in focus and organization, as well as in quality. The mathematics panel expresses concern that many AP and IB mathematics teachers have insufficient professional development opportunities to derive both mathematical content and pedagogical knowledge or to receive help in implementing modifications to the programs. Having reviewed a significant sampling of AP summer institute materials (1998–2000), the panel finds that many of the workshops did not adequately address substantive issues relevant to teaching calculus. The science panels note that few of the AP workshops, even those that emphasized laboratory experiences, focused on inquiry.⁷ The panels commend the IBO for its professional development activities related to internal assessments that focus on inquiry.

⁷Inquiry includes laboratory investigation, but also a broad array of information gathering, appraisal, and testing of ideas toward the goal of understanding science deeply.

The College Board and the IBO are just beginning to fully develop vehicles for establishing professional communities of learners among geographically separated teachers. The primary means being used are discussion groups and databases that can be accessed on the Internet. However, the committee notes that both the College Board and the IBO have regional organizations for teachers. Some are more active than others, and each provides different types of activities. For example, the IBO has a vibrant group in Florida that runs its own conferences, and the College Board, through its regional offices (notably in the southwest), provides opportunities for teachers in the regions to work with colleagues in professional development activities throughout the school year. Nonetheless, there are too few opportunities for teachers to interact with colleagues on issues important to teaching. This is especially true in high schools where AP or IB teachers in a particular discipline may be the only members of their departments who teach these courses.

The National Commission on Mathematics and Science Teaching for the 21st Century (2000, pp. 27–28) provides some suggestions that could become part of AP and IB Web-based efforts. These include the creation of (1) an online professional journal that would encourage teachers of advanced mathematics and science to engage in publishable research and to share new teaching strategies with colleagues, both nationally and internationally; (2) a dedicated database of teaching ideas, plans, and other resources; (3) an interactive online resource for conversations, meetings, and idea sharing; and (4) interactive videos for observing good teachers and critiquing teachers' own efforts, for mentoring, and for online instruction. Research is needed to determine the effectiveness of such Web-based mechanisms for teacher professional development.

CONCLUSION

The committee has advocated the use of a model that can help sponsors of advanced study programs make decisions on how their programs can best improve in the years ahead. This model includes both principles of learning and design principles for curriculum, instruction, assessment, and professional development. The committee believes that if programs of advanced study, such as AP and IB, were to place principles of learning at the center of their own implicit models, the programs would improve in quality and effectiveness with regard to fostering deep understanding. Program quality would also be enhanced if the programs were to recognize the systemic and mutually interactive nature of curriculum, instruction, assessment, and professional development. With care, persistence, and a strong guiding model, advanced study programs could become worthy beacons for all of American education.

10

Uses, Misuses, and Unintended Consequences of AP and IB

This chapter examines a number of ways in which the Advanced Placement (AP) and International Baccalaureate (IB) programs and their assessment results are used. Some of these uses are appropriate and intended by the program sponsors; others are not. Unintended uses are making these programs high stakes in terms of their consequences for students, for teaching and learning, and for schools.

HIGH STAKES

In 1998, *Newsweek* published a list (Mathews, 1998a) entitled “The 100 Best High Schools in America.”¹ This list, which ranks public high schools according to the number of AP and IB tests taken, divided by the number of graduating seniors, was drawn from the book *Class Struggle: What’s Wrong (and Right) with America’s Best Public High Schools* (Mathews, 1998b). The ostensible purpose of the list, now published annually for Washington area schools in the *Washington Post*, is to quantify the level of challenge high schools provide to their students. The author of the list acknowledges that such rankings have their limitations, but believes it is better to have such a tool, even one that may be misleading, than to have no means of comparing schools and motivating parents and students to demand more from their schools (Mathews, 1998b).

The practice of ranking schools by the number of AP or IB tests administered, as *Newsweek* does, or using students’ scores on AP or IB exams for evaluating teachers or comparing the quality of teachers and schools, as some parents, school administrators, or policymakers may do, is making these programs high stakes in ways the program developers never intended.

¹The list does not include public schools that admit more than half of their student body through a competitive process that includes examinations or other academic criteria.

Such misuses of AP and IB assessments are both educationally inappropriate and counter to the Standards for Educational and Psychological Testing (American Educational Research Association [AERA]/American Psychological Association [APA]/National Council on Measurement in Education [NCME], 1999). Moreover, neither the College Board nor the International Baccalaureate Organisation (IBO) has to date provided sufficient guidance to counter many of these misuses. This section considers some of the unintended consequences of these practices.

Effects on Students

Making decisions about the effectiveness of teachers or the quality of their teaching primarily on the basis of AP or IB test scores may have unintended consequences for students. For example, if teachers are evaluated on the basis of AP or IB test results, they may discourage certain students from taking AP or IB courses because they believe those students will not perform well, or they may counsel students for whom they anticipate a low grade to skip the final examination. Such practices can deny students the opportunity to try an AP or IB course or to validate what they have learned in comparison with nationally or internationally established standards.

Effects on Teaching and Learning

Teachers who are evaluated on the basis of student test results are more likely to teach to the test than to teach what they deem important (see, for example, Koretz, 1988, 1996; Koretz, Linn, Dunbar, and Shepard, 1991; Linn, Graue, and Sanders, 1990; Shepard, 1990; Shepard and Cutts-Dougherty, 1991). The committee acknowledges that the nature of the AP and IB programs makes teaching to the test the norm; the test specifications are the curriculum (see Chapter 3, this volume). However, the committee does not believe the AP and IB tests reviewed for this study sampled broadly and deeply enough across the full range of content knowledge, conceptual understanding, processes, and skills valued in the respective disciplines to make teaching to the test an appropriate strategy for developing the level of conceptual understanding that should be the goal of advanced study.

Therefore, the panels and the committee view teaching to AP and IB tests as potentially interfering with teaching what is truly important for enhancing student learning. For example, the mathematics panel notes that the AP and IB examinations have overemphasized procedure and underemphasized application and conceptual understanding. The chemistry panel also identifies a lack of contextual problems in the AP examinations. The biology and physics panels find that both the AP and IB assessments cover too much content, and the chemistry panel decries the lack of attention to

important interdisciplinary connections. The biology and chemistry panels note a lack of test items that measure laboratory skills on the AP examinations, and the physics panel indicates that neither AP nor IB assessments require students to apply what they learn in class to solve new or novel problems. In sum, teaching to AP and IB tests for the purpose of raising test scores can lead to superficial coverage of a broad base of content knowledge, to teachers ignoring the importance of meaningful inquiry-based and laboratory experiences (AP only), and to students feeling that what they are learning in school has little application to the real world.

Effects on Teachers

Inferences about teacher quality and effectiveness cannot be supported by data drawn solely, or even primarily, from AP and IB test scores. One important reason for this is that students come to AP and IB classrooms with different levels of skill and mastery of content that make it difficult to determine the effects of a single teacher's work on student achievement in any particular year. A well-prepared group of students might, for example, earn high scores on their AP or IB final examinations even if the quality of the teaching in their class was low. Similarly, an underprepared group of students might do quite poorly on AP or IB assessments because of their previous preparation, despite the valiant efforts of a highly qualified and dedicated AP or IB teacher. Although this is the case for all subjects, it appears to be especially true for advanced mathematics because of the hierarchical and sequential nature of the subject.

Effects on Schools

Ranking Schools by the Number of AP or IB Tests Taken

Policymakers and others often rely on numbers, rankings, comparisons of standardized test results, and other quantifiable data to draw conclusions about the state of education in the United States. The media report these data as valid and scientific, and the public uses them as a basis for making important decisions and judgments.

For example, the annual list described at the beginning of this chapter has been used by many as a measure of overall school quality. The list has taken on a life of its own. It is now so important to be included among the top 100 schools on the list that some competitive high schools not included have posted disclaimers on their Web sites indicating why this is the case.²

²An example is City Honors High School in Buffalo, New York; see <http://cityhonors.buffalo.k12.ny.us/city/news/1999-00/0003/news0003newsw/news0003newsw.html> (January 11, 2002).

Many others that are listed among the top 100 openly publicize their ranking as a sign of excellence.

Using the number of AP and IB examinations or number of AP and IB courses offered in a school as a measure of school quality also penalizes in the arena of public opinion schools that have chosen, because of different educational values or priorities, to offer other rigorous options to their students. Ignoring the value of these alternative approaches can stifle creativity and innovation in the development of new programs. Such alternative approaches could be as rigorous as AP or IB and also be more suitable to the student body served by a particular school.

Additionally, ranking schools by the proportion of students who take AP or IB examinations ignores the central issue of how many of those students are adequately prepared through high-quality courses to succeed on the exams. The committee notes that among states and school districts where all AP students are required to take the examinations, a notable number of students may not complete the examination or answer test questions conscientiously.

Evaluating School Quality by the Numbers

The fundamental objective of education is to promote the academic growth of each student. Evaluations of school quality should help identify those schools that are accomplishing this goal and those that are not. When assessment scores are used to evaluate schools, efforts must be made to determine whether the scores are indicative of growth (or lack of growth) that is due to the quality of the instructional program, or merely reflect students' home environments, external learning experiences, and available resources. There are many schools that provide high-quality instruction in school districts where resources are scarce whose students continue to grow academically. There are other schools in which test scores are high, but the quality of instruction may not be as good as in schools with lower test scores. The higher assessment scores may be more reflective of the students' other opportunities than of the quality of the school itself. In sum, relying solely, or even primarily, on AP or IB test scores to evaluate school quality reflects a failure to recognize that there are substantive differences in educational institutions across the nation (see Chapter 2, this volume), while also ignoring the varying characteristics of the students who attend these schools.

QUALITY CONTROL

With increasing calls for educational quality and accountability, educators and policymakers alike have turned to AP or IB to improve the quality

of their schools and curricula. The pressure to introduce or expand AP or IB offerings in high schools can have a number of unintended consequences. For example, schools that claim to offer advanced study programs may or may not be able to support such programs adequately, and the resulting courses may be far from what is intended by the program sponsors. Ensuring the quality and integrity of the AP and IB programs is a complex endeavor that it is frequently affected by factors beyond the control of either the College Board or the IBO.

Standards and Regulation of Courses

The IBO carefully regulates which schools can offer IB courses and how those courses must be structured. As a result, schools are unable to offer IB courses or the IB Diploma without the imprimatur of the IBO.

In contrast, the College Board has no clear standards for what constitutes an AP course or the schools that offer them. This lack of consistency invites misuse of the AP name. For example, schools have been known to label non-AP courses as AP in an effort to make their students more competitive for admission to college. Others may have instituted AP courses without ensuring that they have the facilities and personnel needed to offer a college-level program. Consequently, all four of the panels call on the College Board to certify or regulate AP programs and teachers.

Curriculum Compression

The committee found that schools' efforts to prepare students for AP and IB science and mathematics courses often help stimulate improvements in the prerequisite courses, and that this is an important and positive effect of these programs. However, there also may be some unintended consequences. For example, some students may be adversely affected when schools compress preparatory courses in order to prepare as many students as possible for AP or IB courses. Compression can occur by reducing coverage of specific subjects in a curriculum to provide adequate time for advanced study or by beginning the high school sequence of courses earlier in a student's career.

To illustrate the point, strong preparation is important in mathematics because of the hierarchical and cumulative nature of the subject. However, the mathematics panel notes that there is considerable anecdotal evidence that some students intending to take calculus are rushed through prerequisite courses without thoroughly learning the preparatory material. Mathematical sophistication takes time to develop, and knowledge of a catalog of mathematical facts and techniques is not sufficient. The mathematics panel

notes that most of the students who do poorly in AP or IB calculus did not learn their algebra well enough. These students probably would have been better served by spending more time learning algebra and saving calculus for college. At the same time, there are students who are ready for a rigorous calculus course in high school. Schools need to maintain a delicate balance between meeting the needs of this latter group and pushing too many students into advanced mathematics before they are ready. Achieving this balance is not easily accomplished.

Compression of the curriculum also can occur when students are allowed to skip prerequisite courses and take an AP course as a first course. Among the sciences, AP physics is the course students most frequently select as a first course in the discipline. Data obtained from the College Board (College Entrance Examination Board [CEEB], 2000d) indicate that almost half of all AP physics test takers had had no prior experience with physics before enrolling in the AP course. Thus, the AP course had to cover both a year of high school physics and a year of college physics, making in-depth examination of any topic nearly impossible.

Participation in Examinations

The IBO expects that all students who take IB courses will take the associated examinations. The IBO uses student performance on its examinations to monitor and improve the overall quality of IB programs in different countries and schools. In contrast, the four panels note that the College Board has not developed examination policies or expectations for students' participation in the AP examinations. Because the examinations provide the only external evidence that schools are preparing students in a manner consistent with the College Board's expectations, the panels suggest that a clearly articulated policy is necessary if the College Board is to maintain quality control of the AP name.

Online Courses

As discussed in Chapter 5, advances in technology have made it possible for colleges, universities, technology companies, and other nonprofit and for-profit organizations to create and distribute AP courses and other AP support services, such as professional development for AP teachers, online. Although the reach of these online courses has to date been small relative to other AP opportunities, their potential for growth is unlimited. The biology and chemistry panels are particularly concerned that students who take AP courses online and earn a qualifying score on the examination could earn college credit or placement without having had any hands-on laboratory

experience.³ They call on the College Board to set quality standards for online laboratory components of science courses. It may be noted that, because only authorized schools can provide IB courses, laboratories, and examinations, third-party providers currently cannot offer programs that carry the IB name.

ACCESS AND EQUITY

Disparities in access to AP and IB courses for students who live in inner-city and rural areas are a serious educational and social problem that is discussed throughout this report. However, other students in the United States also lack meaningful access to these courses because their schools deny them the opportunity to enroll.

Limiting Students' Access to AP and IB

Limiting students' access to advanced study occurs in all kinds of educational settings, including the most competitive high schools in America—schools with adequate resources, qualified teachers, and well-prepared students (Mathews, 1998b). These schools, while typically advocating college preparation for everyone, have created layers upon layers of curricular differentiation such that only a select group of students are allowed entrance into certain AP and honors courses; other students are placed in less prestigious courses⁴ (Attewell, 2001; Mathews, 1998b; Oakes and Wells, 2001).

In a recent study, Attewell (2001) finds that many high-achieving students from elite high schools are not able to take the AP courses they would have been able to take had they attended less prestigious schools. He attributes this phenomenon to the fact that many elite high schools provide their best students with opportunities to participate in AP and honors courses while denying access to others. He finds further that, as a function of these placement policies, many highly able students who attend elite high schools are less likely than similar students in other high schools to take advanced mathematics or science courses or examinations. Schools limit participation in part, Attewell contends, because restricting access to AP to the strongest students guarantees that the school's overall pass rate on the final examina-

³Strategies for providing laboratory experiences to online students are discussed in Chapter 5.

⁴Mathews (1998b) estimates that each year, 25,000 interested and adequately prepared students in the United States are told they cannot take AP or IB courses. He further speculates that another 75,000 or more students who have the ability to do well in such courses do not elect to take them because no one encourages them to do so.

tions will be very high, boosting their reputation with the top colleges they care most about influencing.

The committee agrees that AP and IB are not appropriate for all students. Some are not prepared for or do not want to take college-level courses in high school, and such courses are not appropriate for all high school students. However, research shows that there are few rigorous options outside of these classes, especially in high schools with well-developed AP and IB programs (Callahan, 2000). Thus, students who are denied access to or choose not to take these classes are forced to enroll in what are often far less challenging options.

Prerequisites

Prerequisites are frequently used as gatekeepers to regulate enrollment in AP and IB courses. Sometimes this practice is deemed necessary because there is limited space. In other cases, the school simply wants to control which students take the courses to maintain quality (as represented, for example, by high test scores). The committee reviewed more than 100 curriculum guides prepared by individual high schools for their students, parents, and teachers. This review revealed that prerequisite requirements for enrollment in AP or IB courses range from open admission to highly restrictive criteria such as PSAT scores above a certain threshold, all A's in courses leading up to the AP courses, uniformly high teacher recommendations, and evidence of consistently high levels of motivation or excellent work habits. Many of these guides also contain statements to the effect that students who take courses for which they are not recommended must have signed permission from a parent absolving the teacher and the school from responsibility if the student does not succeed. If measures are to be used to extend or restrict access to AP and IB courses, the committee urges that schools demonstrate that their criteria for entry to advanced study are valid predictors of student success.

COLLEGE CREDIT AND PLACEMENT

AP Program

Throughout this report, the committee has challenged the assumption that AP courses uniformly reflect the content coverage and conceptual understanding that is developed in good college courses. We now ask whether students who place out of introductory courses in college on the basis of their AP scores are as well prepared for further study as their peers who take the introductory courses in college.

The College Board has conducted several studies to investigate this question. Recently, Morgan and Ramist (1998) examined the performance of AP and non-AP students in second-level courses in 25 subjects at 21 colleges. These subjects included sciences and mathematics, as well as many others. Breland and Oltman (2001), using data published by Morgan and Ramist (1998), examined the performance in upper-level courses of students who took AP comparative government and politics and AP economics. The conclusion of both of these studies was that students who earned qualifying scores on AP examinations appeared to earn grades in second-level courses that were as good as those earned by students who took the first-level course in college. *However, this conclusion is true only for an overall average.* Further, it was implicitly assumed in these studies that any student with a score of 3 or better on the AP examination would be allowed to take the second-level course. The committee knows from its department survey (see Chapter 2, this volume) that this is not the case. Thus a more precise conclusion for these studies is that *students with qualifying AP scores who were exempted from first-year courses in college appeared, on average, to earn grades in second-year courses that were no lower than those earned by students who took the introductory courses in college.*

With the assistance of an educational statistician,⁵ the committee examined the assumptions, methods, and conclusions of these two studies. This examination revealed that the methodology used in conducting the studies makes it difficult to determine how often and under what circumstances there is a positive advantage for AP students relative to non-AP students in second-level courses. There are two principle reasons for this difficulty:

- The investigators based their conclusions on averages of grades that were computed across classes and institutions to obtain overall averages. No effort was made to control for differences in the types and quality of the institutions involved in the study or for how well the AP courses matched the introductory courses students had placed out of in the different institutions.
- No attempt was made to control for differences among students that could be related to their performance in second-level courses. Examples of such differences include SAT scores (both SAT I and SAT II in the relevant subjects), high school grade point average, whether or not the students intended to major in the subject, and the quality of their overall high school curricula. No evidence is provided in the study reports as to whether stu-

⁵The committee's analysis of the College Board studies was conducted by Bert F. Green, professor of psychology, Emeritus, The Johns Hopkins University.

dents with the same credentials, apart from the AP examination score, also could skip the introductory-level courses with the same positive results in the next-level course.

In conclusion, the methodology used by the investigators to gather and analyze their data makes it difficult to determine whether any apparent advantage held by AP students over non-AP students is a function of the colleges they attend, the classes they enter, their own academic backgrounds and abilities, or the quality of the AP courses they took in high school. Further, there is no way to determine, from the data provided, the number of classes among the various colleges in which non-AP students outperformed AP students. It is possible that AP students were at a disadvantage in some classes or at some colleges.⁶

The committee's analysis of the College Board studies indicates that colleges and universities should not automatically award advanced placement to students with specified AP scores and assume that they will be successful.⁷ Rather, it is more consistent with the evidence developed by the College Board for colleges to adopt policies that consider students individually and in combination with the requirements of the courses into which they seek placement.

IB Program

The practice of awarding university credit and placement for IB Higher Level (HL) courses dates back to at least 1973, when the National Council on the Evaluation of Foreign Student Credentials recommended that U.S. colleges and universities accept IB HL⁸ examination grades for college credit

⁶It might have been more useful to treat the study as a meta-analysis, with each class in which there were AP and non-AP students being treated as a datum. In this scenario, each class would furnish an advantage or disadvantage for AP students with respect to their non-AP classmates. If each class were treated as a datum, standard deviations could be reported, and other class-level characteristics, such as size, instructional methodologies, and the degree to which knowledge gained in a first-level class was important for success in the second-year course, could be analyzed with respect to the performance of AP and non-AP students. Perhaps AP students do better only in small classes, or at selective colleges, or when inquiry is emphasized. Perhaps they do not do better when material from first-level courses is emphasized or when there is a poor match between the AP courses and the introductory courses taught at their colleges.

⁷The Morgan and Ramist and Breland and Oltman studies tell us only that on average, students who are exempted from introductory courses get grades that are as good as those of students who take the first course in college. They do not tell us whether AP students at a particular institution who are exempted from that college's introductory courses have the same depth of understanding of a subject area as students who take the first course at that college.

⁸IB HL courses are taken over a 2-year period (see Chapter 4, this volume).

when foreign students present such grades. Since that time, more than 750 colleges have established policies to accept IB HL credits from students worldwide. According to Paul Campbell, associate director of the International Baccalaureate Organisation of North America (IBNA) (personal communication, March 2000), the number of institutions accepting IB examination scores for credit or placement has increased as a result of individual students petitioning colleges on a case-by case, college-by-college basis.

In seeking credit and placement, many students cite evidence that IB HL courses are comparable to similar AP courses for which colleges and universities routinely grant credit and placement. However, the committee could find no systematic studies that have examined the validity of the claim that AP and IB courses are comparable.⁹ Additionally, the IBO does not design its courses to be similar to introductory college courses, so it is difficult to determine how comparable the two are. Additionally, we know of no systematic studies that compare how well students who score differently on IB examinations perform in upper-level college courses or whether their performance varies by discipline.¹⁰ It is therefore unclear to what extent advanced placement in upper-level college courses is merited on the basis of IB examination scores alone.

More evidence is needed to understand the consequences for students and colleges of awarding advanced placement for AP or IB examination scores. The evidence appears to support the interpretation that a student who earns a high AP score will earn a good grade in an upper-level course in that discipline. However, no evidence has been developed to demonstrate that students who earn qualifying scores on AP or IB examinations have achieved a depth of understanding of the subject comparable to that obtained by students taking the introductory college-level courses. Consequently, the disadvantages that accrue to AP and IB students who decide not

⁹The only study purporting to address the issue of AP and IB comparability was conducted at Case Western Reserve University, where the scores of students who took both AP and IB examinations in the same subject area were compared. The findings indicated that students who scored a 6 or 7 on IB HL examinations scored a 4 or 5 on the AP examination in the same subject area; the reverse was not the case. It may be assumed that all of these students took the IB course and not the AP course since students cannot take an IB examination without having taken the corresponding IB course. The methodology used in the study was not specified.

¹⁰The committee found a summary of isolated studies that examine the overall performance of IB students in college. Some of these studies were conducted at Virginia Polytechnic Institute and State University, University of Florida, and Marquette University. One study that looked at IB students' performance in upper-level science and mathematics courses revealed that IB students outperformed all other students in terms of overall grade point average and/or grades in upper-level courses (Guild of IB Schools, www.rvcschools.org [August 2000]). However, it is difficult to determine the validity of the study results because information about the methodology used by the investigators is incomplete.

to take an introductory college course in a subject before going on to a second-level course are not known.

CONCLUSION

The potential for misinterpreting and misusing test results and other aspects of the AP and IB programs is high and likely to become higher unless countermeasures are taken. The consequences of such misuses extend to students, teachers, high schools, and institutions of higher education.

The misuse of scores and programs appears less widespread for the IB than for the AP program. This difference likely results from the IBO's maintaining tighter control over its program. In addition, the IB program is offered in far fewer schools in the United States than the AP program, making it more difficult to use data on the former program to draw inappropriate comparative inferences about the quality of schools or teachers. Until the College Board makes a concerted effort to educate the media, policymakers, and the public about correct and incorrect interpretations and uses of its examination results, the kinds of abuses described here, and the consequences associated with them, will almost certainly continue and will probably increase.

As this report demonstrates, advanced study programs have an enormous influence on virtually all other components of the education system in the United States. As the programs are currently structured, some of these influences have worked to improve education. However, serious shortcomings persist. It is incumbent upon all individuals and institutions with a stake in improving advanced study and making it accessible to many more students to do so systematically, collaboratively, and in ways that are consistent with emerging research about learning and effective program design. The next chapter offers a series of recommendations for accomplishing these goals. This set of recommendations emerges from the committee's analysis of existing programs of advanced study; the way these programs influence and are affected by other components of the education system in the United States; and whether the programs' current structures are consistent with the principles of learning and the design principles of curriculum, instruction, assessment, and professional development set forth in this report.

11

Recommendations

Chapters 6 and 7 of this report present a framework for examining programs of advanced study. This framework is based on extensive research on student learning and the implications of that research for the design and integration of curriculum, instruction, assessment, and professional development. In Chapters 8 and 9 this framework is used to analyze the Advanced Placement (AP) and International Baccalaureate (IB) programs; areas in which there is alignment with the principles of learning are highlighted, as are aspects of the programs that deviate from those principles. Chapter 10 provides further analysis through an examination of the uses, misuses, and unintended consequences of the AP and IB programs and examination results.

The present chapter presents a set of recommended actions that could significantly improve existing programs for and approaches to advanced study and serve as the basis for the design of alternatives. *Italic type is used to highlight particular groups to which the recommendations are directed.* However, given the diversity and decentralized nature of the educational system in the United States, the committee leaves specific implementation strategies to local and state education agencies. Similarly, program developers must also decide how to execute our recommendations within the unique structures of their respective organizations. The committee's first and most important recommendation articulates a principle concerning the goals of advanced study and is addressed to all those involved in developing or teaching advanced study courses.

RECOMMENDATION 1: THE PRIMARY GOAL OF ADVANCED STUDY

The primary goal of advanced study in any discipline should be for students to achieve a deep conceptual understanding of the

discipline's content and unifying concepts. Well-designed programs help students develop skills of inquiry, analysis, and problem solving so that they become superior learners.

It is not enough for students to achieve familiarity with factual content alone; they need to understand the central ideas of the discipline in order to build a conceptual framework for further learning and apply what they have learned to new situations and to other disciplines. A consequence of this principle is that accelerating students' exposure to college-level material, while appropriate as a component of some secondary advanced study programs, is not by itself a sufficient goal. Except for a small number of highly able students, courses that pursue acceleration as the sole objective may proceed too quickly for many students to develop deep conceptual understanding.

RECOMMENDATION 2: ACCESS AND EQUITY

Schools and school districts must find ways to integrate advanced study with the rest of their program by means of a coherent plan extending from middle school through the last years of secondary school. Course options in grades 6–10 for which there are reduced academic expectations (i.e., those that leave students unprepared for further study in a discipline) should be eliminated from the curriculum. An exception might be made for courses designed to meet the needs of special education students.

Many additional students could benefit from participation in advanced study given improved preparation in earlier years and wider program availability. As documented in Chapter 2, certain racial and ethnic groups (including African American and Hispanic students) are substantially underrepresented among matriculants in advanced courses and among AP test takers, though the causes for this are unclear. A coherent plan that extended across grade levels and schools within a district could enable a higher proportion of potentially qualified students to benefit from advanced study. By treating all students as potential participants while in grades 6–10, schools could help even those who do not eventually enroll in advanced study to emerge with strong foundations in mathematics and science.

The positive effects on student achievement of a high school curriculum that stresses high levels of academic learning for all students have been demonstrated empirically (Lee, 2001; Lee, Burkam, Chow-Hoy, Smerdon, and Gevert, 1998; Lee, Croninger, and Smith, 1997). The committee therefore recommends that *high schools* eliminate low-level, “dead-end” math-

ematics and science courses,¹ which do not afford students the opportunity to prepare adequately for advanced study. Additional support will be needed to make this recommended action work for some students.

Access to advanced study is currently limited in many schools, especially those that are located in rural areas, urban centers, and other localities that enroll large proportions of low-income and minority students. *States, school districts, and program developers* (those who design courses for advanced study) must work to expand these opportunities to all schools. Finally, *districts*, with the support of advanced study programs, must provide substantial professional development opportunities for teachers, invest appropriately in laboratory facilities and materials, and develop academic support systems for those students who need them.

RECOMMENDATION 3: LEARNING PRINCIPLES

Programs of advanced study in science and mathematics must be made consistent with findings from recent research on how people learn. These findings include the role of students' prior knowledge and misconceptions in building a conceptual structure, the importance of student motivation and self-monitoring of learning (metacognition), and the substantial differences among learners.

Program developers should collaborate with discipline experts, researchers in pedagogy and cognitive science, and master teachers to examine existing programs and develop new ones. They should ensure that the components of their programs (curriculum, instruction, assessment, and professional development) are consistent with what is known about how people learn and work together to foster students' conceptual understanding.

RECOMMENDATION 4: CURRICULUM

Curricula for advanced study should emphasize depth of understanding over exhaustive coverage of content. They should focus on central organizing concepts and principles and the empirical infor-

¹The committee chose not to cite such courses specifically by name because (1) the decentralized nature of U.S. education means that school districts title their courses in accordance with their own unique curriculum structure, and labeling conventions making it difficult to name with accuracy all the possible courses to which we refer; and (2) similarly titled courses offered in different school districts could be very different (for example, a course called "general chemistry" could provide adequate preparation for advanced study in one district but not in another). The committee chose, therefore, to define low-level courses as those that leave a student unprepared for further study in the discipline.

mation on which those concepts and principles are based. Because science and technology progress rapidly, frequent review of course content is essential.

Curricula should be focused on a reasonable number of concepts that can be studied in depth during the time allotted. Integration of the advanced study curriculum with earlier courses is essential, because building on earlier experiences can contribute to achieving both breadth of knowledge and depth of understanding over a period of years. It may sometimes make sense for advanced courses to extend over multiple school years to allow sufficient time for this process, as occurs in the IB program.

Identifying organizing principles and structuring them appropriately for advanced learners is labor-intensive and requires varied expertise. Therefore, effective curriculum development must be a collaborative effort conducted by teams of experienced teachers working with curriculum specialists and experts in the disciplines, in cognitive theory, and in pedagogy. The teams need to use a systematic approach to the development process that is aligned with the principles of learning set forth in this report and that involves repeated cycles of design, trial teaching with students, evaluation, and revision.

RECOMMENDATION 5: INSTRUCTION

Instruction in advanced courses should engage students in inquiry by providing opportunities to experiment, analyze information critically, make conjectures and argue about their validity, and solve problems both individually and in groups. Instruction should recognize and take advantage of differences among learners by employing multiple representations of ideas and posing a variety of tasks.

While the quality of instruction depends on the knowledge, creativity, and sensitivity of teachers, *program developers* can do much to suggest possible strategies, and *school administrators* need to provide both material resources and opportunities for professional development if high-quality teaching is to be achieved. Effective ways to use the Internet and other electronic resources should be encouraged and evaluated. In general, the committee recommends careful alignment of instruction with the *National Science Education Standards* (NRC, 1996) and the standards proposed by the National Council of Teachers of Mathematics (NCTM, 1991) and the National Board for Professional Teaching Standards (NBPTS, 2001).

RECOMMENDATION 6: ASSESSMENT

Teachers of advanced study courses should employ frequent formative assessment of student learning to guide instruction and monitor learning. External, end-of-course examinations have a different purpose: they certify mastery. Both types of assessment should include content and process dimensions of performance and evaluate depth of understanding, the primary goal of advanced study (see Recommendation 1).

Since end-of-course assessments strongly influence instruction, *program staff* must ensure that these assessments measure students' depth of understanding and their ability to transfer knowledge to unfamiliar situations. Programs should report the results of their end-of-year assessments in sufficient detail so the results are useful to students in evaluating what they have learned, to colleges in advising students accurately on their course options, and to schools and teachers in improving their advanced study courses and programs. Combining the results of several different indicators instead of relying solely or primarily on the results of a single high-stakes examination can provide a more accurate picture of student achievement.

Program staff should assist teachers in developing formative assessments that measure student progress toward desired learning outcomes. While classroom assessment is primarily the responsibility of teachers, programs can favorably affect student progress and increase teacher effectiveness by suggesting appropriate strategies and providing examples.

RECOMMENDATION 7: QUALIFIED TEACHERS AND PROFESSIONAL DEVELOPMENT

Schools and districts offering advanced study must provide frequent opportunities for continuing professional development so teachers can improve their knowledge of both content and pedagogy. National programs for advanced study should clearly specify and monitor the qualifications expected of teachers. Professional development activities must be adequately funded and available to all teachers throughout their teaching careers.

Professionals in most demanding fields require continuing education to maintain and improve their knowledge over time. The same applies to teachers. Professional development should emphasize deep understanding of content and discipline-based methods of inquiry, provide multiple perspectives on students as learners, and develop teachers' subject-specific pedagogical knowledge and skills. It should treat teachers as active learners,

build on their existing knowledge, and take place in professional communities where colleagues have the opportunity to discuss ideas and practices.

Many groups can contribute effectively to teacher professional development. Discipline-based *professional associations* should help identify the knowledge and skills required for excellent teaching. *Researchers* should investigate the effects of different levels of teacher professional development on student learning and achievement in advanced study. *University and college science and mathematics departments* and *schools of education* must work collaboratively to develop discipline-specific approaches to teacher preparation and continuing professional development. *States*, in monitoring the quality of local education, should collect and report data on the qualifications of teachers of advanced study. *National programs* of advanced study should assume greater responsibility for assisting schools, districts, and states in developing professional development programs and in upgrading their own programs in the ways suggested in this report.

RECOMMENDATION 8: ALTERNATIVE PROGRAMS

Approaches to advanced study other than AP and IB should be developed and evaluated. Such alternatives can help increase access to advanced study for those not presently served and result in the emergence of novel and effective strategies.

Some small-scale alternatives are described in Chapter 5. However, there is much room for new ideas. *Funding and research agencies* should encourage the development of additional advanced study options and should collect and disseminate information about existing alternatives that might become national models.

Little has been said in this report about the special needs of very high-ability students (the top few percent in mathematics and science). However, the committee urges *funding agencies* to sponsor research related to the learning needs of these exceptional students and to support educators in the development of innovative strategies for meeting those needs.

RECOMMENDATION 9: THE SECONDARY–COLLEGE INTERFACE

9(a): When awarding credit and advanced placement for courses beyond the introductory college level, institutions should base their decisions on an assessment of each student’s understanding and capabilities, using multiple sources of information. National examination scores alone are generally insufficient for these purposes.

Legislatures should avoid imposing laws or regulations requiring public colleges and universities to award credit for specified minimum scores on AP or IB examinations. *Offices of college admissions* should emphasize that taking advanced study courses without doing well in them or without taking the exams is insufficient. *Program developers* should clearly discourage anyone from using their programs and assessment results to draw inappropriate inferences about teachers, schools, and communities.

9(b): College and university scientists and mathematicians should modify their introductory courses along lines similar to those proposed in this report for high school advanced study. Departments should carefully advise undergraduates about the benefits and costs of bypassing introductory courses.

It is still common in some introductory college science and mathematics courses to cover large numbers of topics relatively superficially and with little connection to the world in which the topics are applied, thereby encouraging memorization at the expense of developing deep understanding of concepts and principles. These courses need to be brought into alignment with Recommendations 4 through 6, in part because teachers' ideas about how to teach science and mathematics come from their own college experiences.

Many students who participate in secondary advanced study later enroll in introductory college courses. Therefore, these college courses need to evolve so that they will continue to be appropriate for audiences with diverse preparation.

RECOMMENDATION 10: CHANGES IN THE AP AND IB PROGRAMS

10(a): The College Board should abandon its practice of designing AP courses in most disciplines primarily to replicate typical introductory college courses. The committee endorses recent moves by the College Board in this direction. As noted in particular in the report prepared by the calculus panel for this study, the College Board now bases AP calculus on expected outcomes and emerging best practices in college and university courses, rather than on lists of topics to be covered and tested. This approach, embraced by most of the mathematics professional communities, can serve as a model for revisions in other subject areas.

10(b): The College Board and the IBO should evaluate their assessments to ensure that they measure the conceptual understanding and complex reasoning that should be the primary goal of advanced

study. Programs of validity research should be an integral part of assessment design.

10(c): Both the College Board and the IBO should take more responsibility for ensuring the use of appropriate instructional approaches. Specifying the knowledge and skills that are important for beginning teachers and providing models for teacher development are likely to advance teacher effectiveness.

10(d): The College Board should exercise greater quality control over the AP trademark by articulating standards for what can be labeled an AP course, desirable student preparation for each course, strategies for ensuring equity and access, and expectations for universal participation in the AP examinations by course participants. When necessary, the College Board should commission experts to assist with these tasks.² These standards should apply whether AP is offered in schools or electronically.

10(e): The College Board and the IBO should provide assistance to schools in their efforts to offer high-quality advanced courses. To this end, the College Board should provide more detailed curriculum, information about best practices for instruction and classroom assessment, and strategies for enhancing professional development opportunities.

10(f): The College Board and the IBO should offer more guidance to educators, policymakers, and the general public concerning proper uses of their examination scores for admission, placement, and teacher evaluation. They should also actively discourage misuse of these scores.

10(g): The College Board and the IBO should develop programs of research on the implementation and effectiveness of their programs. This research should address such questions as the following: What is the preparation of teachers in these programs? What instructional strategies are actually used in practice, as indicated by classroom observation? How effective are the AP and IB professional development activities? How do the programs affect other school offerings and the curricula of the preceding years? How do students who participate in the AP and IB programs fare in college as compared with students lacking this experience? How are their choices of college courses affected? How do students fare who take the

²The committee notes that the College Board has used this strategy in the past. For example, in 1997 the National Task Force on Minority High Achievement was convened to assist the College Board in outlining recommendations for substantially increasing the number of African American, Latino, and Native American undergraduates who achieve high levels of academic success.

courses but not the exams? What is the impact on colleges of the large numbers of students earning credit through advanced study? Answers to such questions are urgently needed if the programs are to improve. Given the large and growing investment in this segment of secondary education, a substantial research effort is justified. Both *public and private agencies* should be prepared to assist in sponsoring this research. The various parties, including *the agencies and the programs*, should consider how to ensure independent review of the results. The *College Board and the IBO* should develop ways to incorporate the results of this recommended research systematically into the ongoing improvement of their programs.

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Appendix A

Overview of Panel Findings and Recommendations

INTRODUCTION

A major goal of this project was to understand advanced study as it is currently implemented in the sciences and mathematics. Accordingly, the National Research Council (NRC) charged the committee with examining advanced study in biology, chemistry, physics, and mathematics (with an emphasis on calculus). The largest advanced study programs for high school students in these disciplines are part of the Advanced Placement (AP) and International Baccalaureate (IB) programs. Because the four subjects are so different, four independent panels of experts in these disciplines were convened to advise the committee.

Panel Composition and Charge

The four panels were assembled using the normal process for appointing all NRC committees: a slate of qualified individuals was identified on the basis of recommendations from a variety of sources and submitted to the NRC for approval. Each panel included an educational researcher with a strong base in the discipline, an accomplished university teacher-scholar in the discipline, and a secondary teacher involved with advanced programs in the discipline. A member of the study committee chaired each panel, and a senior member of the committee's staff provided assistance and expertise at each of the panel meetings. The chair of each panel served as liaison to the committee. The names of the panel members and chairs are listed at the front of this report.

The charge to the panels (reproduced in Annex A-1 at the end of this appendix) included addressing all the major areas under the full committee's charge, including evaluation of the AP and IB programs in light of what is known about cognition and learning and the nature of the particular disci-

pline, identification of major conceptual issues that should serve as curricular foci, means of balancing breadth and depth, interdisciplinary connections, quality of assessments, teaching methodology, comparison with national standards, and preparation of high school students for further study at the college level. The panels were not asked to consider programs other than AP and IB because of time limitations.

Each panel met for two 2-day sessions during the spring and summer of 2000. Prior to each meeting, panel members received general information about the AP and IB programs, as well as materials more specific to their disciplines. These materials included curriculum guidelines; questions from final examinations that had been released by the College Board and the International Baccalaureate Organisation (IBO); and, for the science panels, laboratory manuals used in AP and IB science courses. Panel members also examined other information about research on learning, curriculum, assessment, and teacher education and professional development. Copies of salient national reports, such as *National Science Education Standards* (NRC, 1996) and *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000), were provided as well. Panel members also applied their personal knowledge and experience with the two programs in formulating findings and recommendations.

Review and Interpretation of Panel Findings and Recommendations

The chair of each panel assumed responsibility for drafting a report and consulting with panel members to incorporate their suggestions and secure their agreement on the report contents. Each panel report underwent an independent, monitored review by reviewers external to the NRC. The chair of each panel then assumed primary responsibility for preparing the panel's response to review, along with appropriate changes.

The panels' findings and recommendations represent the consensus of the panel members. Reviewers agreed that the findings are well substantiated. The committee acknowledges, however, that different groups of experts might have arrived at somewhat different recommendations regarding desirable changes. In other words, there may be several solutions to some of the problems that were noted.

Since the recommendations of the panels are discipline-specific, the committee did not have the expertise to consider each recommendation in detail. However, the panels' findings were an important part of the evidence used by the committee in analyzing advanced study programs and in reaching agreement on the recommendations presented in Chapter 11 of this report.

As might be expected when four groups of disciplinary experts evaluate educational programs in their subject areas, there are both substantial common elements and significant differences among the panel findings. Problems found to be critical in one discipline are not necessarily important in others. Since each panel undertook its work altogether independently of the others, the common elements are particularly worthy of note. Following a review of some of these common elements, the findings and recommendations of the four panels are presented.¹

COMMON ELEMENTS IN THE PANELS' FINDINGS

All of the panels find considerable merit in both the AP and IB programs, which provide challenging opportunities for motivated students that might not otherwise be available. The panels also note major deficiencies in both programs that they believe need to be addressed. The AP calculus program is further along in the process of improvement than are the AP science programs.

Research on Learning: All of the panels agree that the AP and IB programs are not yet effectively utilizing what is known about how people learn in developing their courses and their assessments. The science panels also note that the programs are not consistent with national standards such as those presented in *National Science Education Standards* (NRC, 1996). Although the programs emphasize the importance of higher-order learning and thinking, the amount of content to be covered and assessed, particularly in the sciences, tends to encourage rote memorization rather than conceptual learning. The programs do not yet stress the need for teachers to understand and correct students' misconceptions. The science panels note that the AP program misses important opportunities to promote interdisciplinary connections between mathematics and the sciences and between different sciences. At present, the IB program does a somewhat better job of recognizing these linkages through its Group 4 Project and its internal assessments in the sciences.

Examinations: AP and IB curricula are designed to prepare students for successful performance on end-of-course examinations. The content and structure of the examinations, therefore, have a profound effect on what is taught and how in AP and IB classrooms. The science panels agree that the examinations for AP and IB have some deficiencies. Most serious of these is

¹The full report of each panel, including substantial analysis and supporting material, is available online at www.nap.edu/catalog/10129.html. Those interested in a particular discipline should download the corresponding report.

that, in the science panels' judgment, exam questions do not test conceptual understanding adequately, a situation that adversely affects learning to the extent that classroom instruction is guided by the examinations. The mathematics panel indicates that both the AP and IB mathematics assessments require conceptual understanding, but both examinations could focus on assessing such understanding to a greater degree. Making the AP calculus examinations less predictable, for example, would encourage teachers to teach concepts rather than problem types.

Evolution of Course Content and Technology: The biology and chemistry courses in the AP and IB programs do not adequately reflect the evolution of these disciplines over the last two decades. The physics courses also include substantial amounts of older material, but the physics panel does not judge this to be a compelling problem relative to other concerns. Technological advances, especially in the application of computers, are causing major changes in all of the disciplines and generating novel instructional possibilities that are not yet adequately reflected in course content.

Teacher Preparation: All four panels note that neither the College Board nor the IBO has provided clear expectations for teacher preparation, that qualified teachers are in short supply, and that better teacher preparation is a prerequisite for substantial program improvement.

Student Preparation: All of the panels note the potential for inadequate student preparation for advanced study. In some cases preparation time has become compressed to allow time for the advanced programs. Indeed, as the programs have grown, they have affected the entire high school science and mathematics curriculum. Furthermore, a significant number of students are taking AP science courses as the first course in the discipline, particularly in physics. Additional discussion of these issues is presented in Chapters 2 and 10 of this report.

The Secondary–Postsecondary Interface: Finally, all the science panels believe there is insufficient cooperation and communication between high schools and universities with regard to structuring secondary advanced study for students who will enroll in advanced science and mathematics courses when they enter college. The mathematics panel, on the other hand, views cooperation and collaboration between high schools and colleges as a strong point of the AP program. The mathematics panel credits the College Board with facilitating communication among all stakeholders with regard to the teaching of calculus. In all disciplines increased cooperation could lead to improvements in the structure of secondary advanced programs, better teacher preparation and professional development, and college course sequences that are appropriate for students having different experiences in high school.

BIOLOGY PANEL

Principal Findings

Curriculum

Finding: The AP course outline is not up to date, and it overemphasizes environmental, population, and organismic (EPO) biology at the expense of molecular, cell, developmental (MCD) and evolutionary biology. Although similarly out of date, the IB curriculum achieves a more appropriate balance between the EPO and MCD areas. The AP curriculum should include more on the process of science, including the responsible conduct of research, and the core IB curriculum should include more evolutionary biology. The core curricula of both programs should be updated to include concepts from current areas of rapid progress, such as genomics, cell signaling, mechanisms of development, and molecular evolution.

Finding: A major problem with the AP course is that pressure to cover all of biology in less than a year precludes in-depth study and leads to superficial knowledge. In contrast, the IB program allows time for some in-depth study by subdividing the curriculum into core and options, and by allowing 2 years for the Higher Level (HL) course. The AP course needs to include more options, both in the curriculum and on the tests, to make the breadth covered manageable. One solution would be to have two AP courses—one emphasizing EPO and the other MCD biology—both with significant evolutionary emphasis.

Finding: Both AP and IB have stated themes around which the courses are theoretically organized. The eight themes of the AP curriculum mix philosophy and content, with some redundancy in the content themes, but appear to be adequate for their stated purpose. In the IB curriculum, there are only four stated themes, which surprisingly do not include two that appear essential—energy transfer and heredity. Themes in both courses are intended to provide integration of different topics, but the extent to which these themes are used in presenting subject matter generally depends on decisions made by individual teachers. Particularly in AP courses, better integration of topics is needed.

Finding: Meaningful learning in biology must involve inquiry-based laboratory experiences that require students not simply to carry out a technique or learn a laboratory skill, but also to pose questions, formulate hypotheses, design experiments to test those hypotheses, collaborate to make experiments work, analyze data, draw conclusions, and present their analyses and conclusions to their peers.

Finding: There is little evidence of interdisciplinary emphasis in the AP course outline. In contrast, the entire IB program, including its biology component, rests on the importance of interdisciplinary connections in learning. The IB program is exemplary and far superior in this regard. The AP program should consider changes that would promote interdisciplinary learning.

Instruction and Professional Development

Finding: AP courses and to a somewhat lesser extent IB courses generally rely on the traditional transmission–reception mode of instruction rather than a constructivist model in which students develop their own conceptual framework through inquiry-based, problem-centered active learning (as recommended in the *National Science Education Standards* [NRC, 1996]). Both programs need to effect changes in the teaching approaches used.

Finding: The way the AP and to a lesser extent the IB courses are taught is inconsistent with current knowledge in several ways: rapid-fire course coverage at the expense of depth of understanding; continued reliance on the traditional passive-learner, transmission–reception model of learning; failure to specifically target common known misconceptions; limited use of history as a route to understanding in the context of people and society; failure to keep pace with new technological and instrumentation opportunities, such as learning through computer modeling of biological systems and hand-held data collection and analysis equipment for field work; over reliance on multiple-choice and fill-in-the-blank test questions; and limited experiential and inquiry-based learning in the laboratory, including the “persuasion of peers” phase crucial to the scientific process. In general, the application of research-based learning theory to the design of instruction and assessment is lacking.

Finding: A greater emphasis on inquiry-based learning in AP and IB courses might motivate more students to pursue further training in biology and biology-related careers.

Finding: Many teachers at the secondary level are unprepared to teach college-level biology with regard to content knowledge, and many schools that offer AP programs do not have the resources to support adequate laboratory instruction. The College Board should evaluate and certify AP schools and teachers in some manner.

Finding: More in-service preparation and support are needed, and more attention should be paid to pedagogy in manuals and workshops, particularly for AP teachers.

Assessment

Finding: AP and IB final examinations primarily measure rote learning when assessing students' mastery of content knowledge, concepts, and applications. However, in the IB assessment process, evaluation of a portfolio, laboratory notebooks, and other work provides more perspective. The AP exam should include more free-response questions and evaluation of laboratory work, and the examinations for both programs should test more concept knowledge. With regard to application of knowledge to other courses and situations, the AP exam is limited by a lack of interdisciplinary emphasis, while the IB assessments include such applications. As noted above, the AP course and exam would benefit from more interdisciplinary emphasis.

Finding: The perceived need for comprehensiveness and the single high-stakes exam of the AP program in particular encourage teachers to promote rote learning in order to cover all the necessary material.

Finding: Both the AP and IB examinations emphasize assessment of what is easily measured: rote learning of facts and concepts, rather than what is most highly valued—hierarchically structured conceptual knowledge and understanding of scientific processes.

The Secondary–Postsecondary Interface

Finding: University-sponsored outreach programs can be a major resource for high school advanced biology programs and should be encouraged. More communication between high schools and universities—in both directions—would be helpful in fulfilling the needs of both institutions and in developing curricula and assessments.

Finding: There are many concerns with the use of AP and IB scores for granting of advanced placement. Some top-ranked colleges do not accept either AP or IB credit or both. For a variety of reasons discussed above, some AP and IB biology courses are not of high enough quality to be appropriate for college credit. The AP biology course as presently constituted is too EPO-oriented to be an appropriate substitute for a first-year college MCD-oriented biology course.

Finding: Because of the lack of in-depth study in many AP courses, students who place out of first-year college courses may be at a disadvantage later at institutions where the introductory course is taught effectively. The available data on how well the AP courses prepare students for advanced work in the field may be misleading.

Recommendations

Overall Recommendation: The College Board should certify schools and teachers that wish to offer AP biology courses and should provide suitable training opportunities for prospective AP biology teachers. The College Board should also develop procedures for ongoing assessment of AP programs and teachers through regular sampling of student work; such sampling should also be used for assessment of student achievement in addition to the final examinations.

Overall Recommendation: Certification and assessments of both the AP and IB programs by the College Board and the IBO, respectively, should be designed to ensure that changing emphases in standards for teaching, professional development, assessment, and content, as set forth in the *National Science Education Standards* (NRC, 1996), are being implemented. Teacher preparation and in-service workshops in both programs should place more emphasis on pedagogy—how to facilitate student-centered, problem-oriented, inquiry-based learning—and on recent results of research on cognition and learning.

Overall Recommendation: Colleges and universities should be strongly discouraged from using performance on either the AP or IB examination as the sole basis for automatic placement out of required introductory college courses for biology majors and distribution requirements for nonmajors.

Curriculum

Recommendation: Students should in general not be allowed to take AP biology as a first science course in high school. A prior biology course should be a prerequisite for AP biology, and a prior chemistry course should be strongly urged as well. In schools where the latter is impractical, chemistry should be a corequisite course.

Recommendation: Both the AP and IB curricula should be updated to include topics of major current interest in biology, such as cell signaling, development, genomics, molecular systematics, and their evolutionary implications.

Recommendation: The AP curriculum should be better balanced, with more emphasis on molecular and cell biology. The IB core topics should include more evolutionary biology.

Recommendation: The College Board should seriously consider offering two different AP biology courses, one emphasizing MCD and the other EPO biology, with two corresponding exams. These courses should go into depth in one of these areas of emphasis and present the basics of the other. Both courses should include a strong emphasis on evolution.

Recommendation: More curricular flexibility should be built into the AP program so that students can study fewer areas in greater depth than is possible with the current overemphasis on breadth of coverage.

Recommendation: The AP program should place more emphasis on laboratory work by developing a new and larger set of innovative, inquiry-based laboratories that conform to the *National Science Education Standards* (NRC, 1996) and by including more laboratory-based questions on the exam. Enough laboratories should be available so that teachers have the opportunity to select among them according to their interests and those of their students, and the laboratory-related questions on the AP exam should be general enough so that teachers have real flexibility in deciding which laboratories to offer. In addition, the AP program should include a mandatory 1-week workshop on laboratory pedagogy for beginning teachers of AP biology and should provide more ongoing laboratory training for established teachers.

Recommendation: Assessments of schools and teachers should include determination of the amount and quality of the laboratory experience being provided. Scheduling of at least one 2-hour laboratory period per week should be strongly urged as a criterion for certification of an AP biology course.

Recommendation: The AP program should promote more interdisciplinary activities that relate AP biology to other academic work, as well as local and regional issues.

Assessment

Recommendation: The AP program should modify its assessment process to incorporate evaluation of laboratory portfolios and other samples of student work prior to the examination. There also should be more questions on the exam designed to test understanding of major concepts and the process of laboratory research, with less emphasis on rote memorization of facts.

Recommendation: To provide feedback, the AP program should make individual students' exam answers available to their teachers after the examinations have been evaluated.

The Secondary–Postsecondary Interface

Recommendation: More attention should be paid to the interface between advanced high school and college biology teaching. In particular, more communication and collaboration should be encouraged between college and university departments and high school teachers of biology. Col-

leges and universities are potential sources of enrichment and resources for high school courses, and college instructors can benefit from the teaching experience of high school teachers. The need for reform is systemic. Like the AP and IB programs, colleges and universities should revise or improve introductory biology courses as necessary to bring them into line with the recommendations made in this report for high school advanced study courses.

CHEMISTRY PANEL

Principal Findings

Finding: The AP and IB final examinations are formulaic and predictable in their approaches and question types from year to year. Thus, with sufficient practice on how to take such examinations and enough drill on major concepts that the examinations are likely to test, students can score well without actually understanding the major concepts associated with the topics being tested.

Finding: The AP and IB chemistry courses do not yet recognize the increasingly interdisciplinary nature of modern chemistry; its incorporation of important related fields, such as materials science and biochemistry; and the opportunities presented by such fields to teach related chemical concepts in a contextual manner.

Finding: The AP and IB examinations do not reflect recent developments in chemistry and in the teaching of chemistry at the college/university level.

Recommendations

Overall Recommendation: Advanced study options in high school chemistry should not necessarily be tied to the potential for earning college/university credit.

Overall Recommendation: Advanced study of chemistry at the high school level should provide students with a coherent, rigorous course that promotes further scientific literacy and prepares students to become part of a highly technological workforce, regardless of whether they continue studying chemistry at the college level.

Overall Recommendation: Advanced study in chemistry need not be based on AP or IB. Many top high schools for mathematics and science offer alternatives, which should continue to be explored. Where appropriate, college credit can be sought on the basis of passing the placement examination administered by many college or university departments.

Curriculum

Recommendation: Any high school course in chemistry that is labeled as advanced study, whether it is structured according to an established curriculum and assessment (such as AP or IB) or otherwise, should enable students to explore the chemistry concepts and laboratory practices introduced in the first-year high school course in greater depth and, where appropriate, to conduct some form of research or independent inquiry. Under

the guidance of a qualified advanced study instructor, desirable features of such advanced study would include some combination of these characteristics: application of basic ideas regarding complex materials, systems, and phenomena; use of modern instrumentation, methods, and information resources; integration of concepts within and between subject areas, including extensions to other disciplines; use of appropriate mathematical and technological methods; extended use of inquiry-based experimentation; development of critical thinking skills and conceptual understanding; use of appropriate tools for assessment of student performance that reflect current best practices; and promotion of communication skills and teamwork.

Recommendation: With rare exceptions, students should not take advanced chemistry as their first chemistry course in high school.

Recommendation: To be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment embodied in the *National Science Education Standards* (NRC, 1996).

Instruction

Recommendation: Qualified AP or IB teachers should have a B.S. or B.A. degree in chemistry (which includes a two-semester physical chemistry course sequence with laboratories), and preferably an M.A. or M.S. degree in chemistry. The chemistry panel does not view a B.S. in science education as being adequate preparation for these teachers, nor does the College Board.

Recommendation: A qualified advanced study chemistry instructor should have experience with effective current and emerging approaches to teaching and assessment in the subject and their applications to the AP and IB chemistry courses.

Recommendation: AP or IB chemistry teachers should have a working familiarity with teaching technologies (e.g., Web, electronic media, laboratory instrumentation) and their appropriate uses.

Professional Development

Recommendation: Required periodic, funded professional development opportunities, including content instruction, research participation, and pedagogy workshops, should be provided for teachers of advanced courses in chemistry. This recommendation is consonant with the National Commission on Mathematics and Science Teaching for the 21st Century's description of professional development as "a planned, collaborative, educational process of continuous improvement for teachers that helps them to do five things: (1) deepen their knowledge of the subject(s) they are teaching; (2) sharpen their teaching skills in the classroom; (3) keep up with developments in their

fields, and in education generally; (4) generate and contribute new knowledge to the profession; and (5) increase their ability to monitor students' work so they can provide constructive feedback to students and appropriately redirect their own teaching" (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, p. 18).

Recommendation: Professional development opportunities, such as the experience of teaching courses or laboratories at colleges or universities and undertaking original research in industry, at government laboratories, or in collaboration with college faculty, would be particularly valuable for AP and IB chemistry teachers. High school–system personnel policies should encourage rather than inhibit such professional development activities during the academic year.

Recommendation: AP and IB chemistry teachers can profit from discussions with each other. School districts and schools should find ways to initiate and sustain such dialogue and to share it with a wider audience. Communication about areas of common interest between chemistry faculties in high schools and those teaching general chemistry in institutions of higher education would be extremely helpful for both communities (see also the recommendations under Vision 4 in *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* [NRC, 1999d]).

Recommendation: AP and IB chemistry teachers should be participating members of professional organizations such as the National Science Teachers Association and the American Chemical Society's Division of Chemical Education.

The Secondary–Postsecondary Interface

Recommendation: Institutions awarding AP examination–based course credit or advanced placement in chemistry should consider doing so only for a grade of 4 or 5, not for a grade of 3.

PHYSICS PANEL

Principal Findings

Overall Finding: The most important goals of advanced physics instruction are independent of the particular topics studied. Advanced physics instruction should be aimed at generating excitement and enthusiasm for further study in physics, at achieving deep conceptual understanding of the subject matter covered, and at instilling in students the scientific habits of mind that are important for their further education in science. Learning any particular physics subject matter is of lesser importance.

Overall Finding: There are far too few data on the long-term outcomes of physics education to allow important decisions about the physics education of large numbers of students to be made with confidence.

Curriculum

Finding: The study of Newtonian mechanics provides an ideal framework for developing the scientific habits of mind and deep conceptual understanding that are the primary goals of advanced physics instruction. Moreover, familiarity with Newtonian mechanics is universally expected of students who have completed an advanced high school physics program.

Finding: The AP Physics B curriculum is too broad for a 1-year course; it allows insufficient time to develop deep conceptual understanding. The IB Physics Higher Level (HL) course covers largely the same material over 2 years—an ideal pace.

Finding: The current AP physics curriculum does not encourage the inclusion of interdisciplinary content in AP physics programs. The IB physics program includes interdisciplinary content as an integral part of the IB program.

Instruction

Finding: More well-qualified teachers are desperately needed for advanced physics programs. With the continued growth of such programs across the nation, there is a severe shortage of qualified individuals to teach them.

Finding: The preparation and skill of the teacher are the principal factors that determine the ultimate success or failure of advanced physics instruction. Thorough understanding of the subject matter is a necessary but not sufficient condition for good physics teaching. Teachers must also be trained in the special pedagogy of physics.

Finding: Skilled physics teachers continuously diagnose the understanding of their students and change their objectives and strategies as that diagnosis indicates. It is impossible to assess the understanding of students without requiring them to explain their reasoning.

Finding: Thorough understanding of the subject matter is a necessary but not a sufficient condition for good physics teaching.

Finding: Traditional “cookbook” methods of laboratory instruction, in which students follow narrowly defined procedures to verify well-known principles, have little effect on students’ conceptual understanding. In contrast, substantial improvements in understanding are possible through rigorous, interactive laboratory experiences.

Assessment

Finding: Current final assessments place too much emphasis on technical problem-solving skills and insufficient emphasis on deep conceptual understanding. For example, very rarely do the scoring rubrics of either AP or IB physics examinations provide for the deduction of credit for incorrect reasoning; correct final results nearly always receive full credit. Also, both AP and IB physics examinations contain too many multipart questions that lead students through the solution instead of requiring students to demonstrate their understanding by solving the problem on their own. On the whole, IB examinations are somewhat more conceptual in nature than their AP counterparts; recent AP examinations are much better in this regard than those of earlier years.

Finding: The scoring of written examinations must emphasize the evaluation of student understanding. Therefore, a rigid scoring rubric in which points are awarded for very specific correct responses to small parts of each question is not appropriate because it reduces the reader’s ability to respond to a student’s thinking (both correct and incorrect) not anticipated by the rubric.

Finding: The pace of IB physics final examinations is much more leisurely than that of their AP counterparts. In general, AP physics examinations require students to do too much in too short a time.

Recommendations

Overall Recommendation: Given the scarcity of data on the long-term outcomes of physics education, an effort should be made as soon as possible to follow the progress of physics students over a period of many years.

Student Preparation

Recommendation: Before enrolling in an advanced physics course in high school, students should have studied the physics that is suggested as a requirement for high school graduation in the *National Science Education Standards* (NRC, 1996). This requirement can be satisfied with the first year of a 2-year physics program (the approach adopted by the IB program).

Recommendation: Before taking advanced physics, students should be fluent in mathematics through the precalculus level. In particular, by the time they are ready to study advanced physics, students should be skilled in algebraic manipulation and have a firm grasp of basic trigonometry. Emphasis should also be placed on the use of proportions to solve problems, estimation skills, the use of international units, and scientific notation (powers of 10).

Curriculum

Recommendation: All advanced physics programs should aim to develop deep conceptual understanding of the topics studied. It is essential that whatever topics are chosen be addressed in depth, with an emphasis on conceptual understanding rather than on technical problem-solving skills. Students must learn that physics knowledge is built on general principles and gain the confidence to apply those principles to unfamiliar situations.

Recommendation: All students of advanced physics should study a nationally standardized one-semester unit in Newtonian mechanics. This unit should have the coverage of current AP Physics C Mechanics (including rotational dynamics), but should not require formal calculus. It should replace the multiple versions currently offered.

Recommendation: In a 1-year advanced physics program, students should study only one major area of physics in addition to Newtonian mechanics.

Recommendation: The AP Physics B program is too broad and should be eliminated as a 1-year course.

Recommendation: Meaningful real-world (laboratory) experiences should be included in all advanced physics programs. There is ample evidence that traditional “cookbook” laboratories do not meet this standard.

Recommendation: Advanced courses should have greater interdisciplinary content and make increasing use of cyberspace and information technology. Modern developments in both science and society as a whole indicate that physicists will be increasingly called upon to address problems that cross the boundaries between traditional disciplines. At the same time, the explosion of information technology provides a vast array of possibilities for improving advanced physics instruction. Teachers and administrators

should be aware of these developments and help advanced physics programs expand their involvement in both areas over time.

Instruction and Professional Development

Recommendation: A concerted effort should be made throughout the physics community to contribute to the preparation and ongoing professional development of highly skilled physics teachers. Peer assessment programs should be implemented for certification and continuing assessment of physics teaching skill.

Recommendation: The panel strongly recommends that explanations of reasoning be required from the first day of an advanced course so that providing such explanations quickly becomes automatic for all students in whatever they do throughout the course.

Recommendation: Information technology should be used to create networks that will enable high school and college faculty and other professionals to share information useful for advanced physics teaching.

Assessment

Recommendation: The scoring of written examinations must emphasize the evaluation of student understanding. As noted above, a rigid scoring rubric in which points are awarded for very specific correct responses to small parts of each question is not appropriate; rather, the reader should evaluate the student's response as a whole. A maximum score should be given only for complete and clear physical reasoning leading to the correct conclusions. The recent trend toward increased emphasis on conceptual understanding should continue.

Recommendation: The standards for success on final assessments should be raised. The panel believes that if its recommended curriculum changes are implemented, successful students will know the material in the new, more manageable curricula thoroughly. Therefore, the panel recommends high standards of performance on the new final examinations.

Recommendation: The panel recommends that sufficient time be allowed for students to complete an entire examination. Final examinations must measure what students know, not how quickly they can recall and apply that knowledge.

MATHEMATICS PANEL

Principal Findings

Overall Finding: The AP and IB programs are both designed to meet the educational needs of highly motivated and well-prepared students, but the origins, goals, purposes, missions, organizations, and structures of the two programs are very different. These differences contribute to variations in the educational expectations, opportunities, and experiences of students and teachers participating in the two programs.

Curriculum

Finding: The AP calculus curricula are largely sound. The recently revised syllabi with more emphasis on conceptual understanding have significantly improved the program, although further change in this direction is desirable. The panel also finds the focus on reasoning to be less than is needed.

Finding: The IB mathematics curricula are largely sound. The portfolio requirement, with its emphasis on applications of mathematics, is likely to introduce a focus on modeling that will benefit IB students. However, the calculus section of the syllabi do not place enough emphasis on conceptual understanding. The panel also has some concern that the breadth of the curricula, although an attractive feature of the program, could lead to superficial learning.

Instruction and Professional Development

Finding: Neither the College Board nor the IBO explicitly articulates in its published materials what it considers to be excellent teaching in mathematics.

Finding: Adequate preparation of teachers for courses leading to calculus or other advanced study options is a critical factor in enabling students to succeed in the advanced courses.

Finding: The availability of high-quality professional development activities and the establishment of support networks for AP and IB mathematics teachers are crucial to promoting and maintaining excellence in these programs.

Finding: U.S. teachers have few opportunities to deepen their understanding of mathematics during the school year, and opportunities during the summer, while useful, tend to be disconnected from everyday teaching.

Assessment

Finding: AP and IB curricula are designed to prepare students for successful performance on end-of-course examinations. The content and structure of the examinations, therefore, have a profound effect on what is taught and how it is taught in AP and IB classrooms.

Finding: The AP examinations have improved under the current syllabi. The effort to promote conceptual understanding by asking nonstandard questions and requiring verbal explanations is excellent. For example, the fact that there is now a wider variety of applications of integration (and not from a prescribed list) encourages students to think about the meaning of an integral. The inclusion of graphing problems involving a parameter focuses attention on the behavior of a family of functions. The variety of representations of a function—by a graph and a table as well as by a formula—promotes better understanding of the concept of function. However, the exam is still predictable enough for many students to do respectably well by mastering question types rather than concepts. The exam does not include enough problems that focus on conceptual understanding. More problems are needed that involve multiple steps, test technical skills in the context of applied problems, ask for interpretation and explanation of results, include substantial realistic applications of calculus, and test reasoning or theoretical understanding.

Finding: The IB exam benefits from being more varied than the AP exams. However, a few exam questions are at too low a level as they ask students to perform algorithms specified in the problem. The exam should include more problems that focus on conceptual understanding, and does not include enough problems that test whether students know which algorithm to apply (e.g., integration by substitution), test technical skills in the context of applied problems, ask for interpretation and explanation of results, and include substantial realistic applications.

Finding: The problems on the AP and IB assessments are too predictable. This encourages teachers to focus on helping students recognize and solve particular problem types. A less predictable examination would encourage instruction focused on the development of students' critical thinking and problem-solving abilities.

Finding: Both AP and IB examinations lack good applications and connections to the real-world uses of mathematics. The IB examinations appear weaker than the AP examinations in this regard.

Finding: Students who do not take the examination at the conclusion of an AP or IB course miss the opportunity to pull the material together for themselves. They also have a negative effect on the experience of other students by making the course appear to be less serious.

Impact of Calculus

Finding: The adequacy of the preparation students receive before taking calculus has an effect on whether they can understand or merely do calculus. Without understanding, students cannot apply what they know and do not remember the calculus they have learned.

Finding: Many teachers and schools are under great pressure to compress algebra and trigonometry so they can prepare as many students as possible for calculus. Sometimes students spend too little time mastering the prerequisite knowledge and skills. The performance of many calculus students is undermined by the fact that they do not learn pre-calculus thoroughly or learn to solve problems and think mathematically. Thus, the rush to calculus may curtail their future options to pursue mathematics, science, and engineering. It is important to realize that it is not the structure or curriculum of AP calculus that causes this problem, but the ways in which the program are used.

Finding: There are not enough checks in the system to ensure that students have the prerequisite algebra, trigonometry, and precalculus skills necessary for success in calculus and courses beyond.

Finding: The courses that precede calculus are often designed to help students make a smooth transition to an AP course. The topics and speed of prerequisite courses are determined by what is needed for AP. Even schools that do not offer AP calculus usually teach from books and curricula that are used in other schools to prepare students for this course. Thus, the AP curriculum influences many more courses and many more students than those who take the AP examinations.

Finding: Most college and university placement and credit practices that are based on student performance on AP or IB calculus examinations are reasonable.

Finding: Data on the number of AP and IB courses offered by schools and the results of the examinations are sometimes used in ways for which they were not intended, thus creating situations that can be detrimental to student learning (see also Chapter 10, this volume).

Recommendations

Preparation of Students

Recommendation: All calculus taught in high school should be at a college level.

Recommendation: All students who enroll in AP calculus should have had at least 4 years of college preparatory mathematics prior to AP calculus.

The structure of IB mathematics courses is different, and this recommendation is not applicable to them.

Recommendation: Strategies must be developed to ensure that students who enroll in calculus have an adequate background in algebra and trigonometry for subsequent work in mathematics and science.

Instruction and Teacher Professional Development

Recommendation: On-going professional development opportunities should be improved, expanded, and made available to all AP and IB teachers.

Recommendation: Schools that choose to offer AP and IB programs must find ways to encourage all teachers to take part in professional development, perhaps by providing time during the school day rather than on nights and weekends.

Recommendation: The College Board should consider developing procedures to certify AP calculus teachers.

Assessment

Recommendation: The AP and IB examinations should vary more from year to year. If teachers expect that major ideas will be assessed rather than specific problem types, it is likely that instruction will encourage the development of students' critical thinking and problem-solving abilities. The AP and IB examinations must strike a balance between judging students' conceptual understanding by asking unfamiliar probing questions, and alarming teachers and students with a strange and unfamiliar test.

Recommendation: Both the AP and IB programs should maintain and increase their focus on conceptual understanding in their assessments.

Recommendation: To assess computational and procedural knowledge, students should be asked questions that demonstrate their ability to use these procedures in solving complex problems.

Recommendation: All students enrolled in AP and IB courses ordinarily should take the relevant external examinations as part of the course requirements.

Recommendation: Both AP and IB examinations should place more emphasis on realistic applications, including those in which students must set up the mathematical model.

ANNEX A-1 CHARGE TO THE CONTENT PANELS

Charge to the Parent Committee and Content Panels: The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the biology, chemistry, physics, and mathematics programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines.

Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the committee's charge and study questions.

The panels should focus on the following specific issues in advising the committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facilitate retrieval and application in new contexts (see, for example, NRC, 2000b).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?
2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?
3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of cov-

erage with in-depth study of important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?

4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's Laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?

5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?

6. To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:

- (a) students' mastery of content knowledge;
- (b) students' understanding and application of concepts; and
- (c) students' ability to apply what they have learned to other courses and in other situations.

2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience and independent investigation)?

2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The *National Science Education Standards* (NRC, 1996) and the NCTM Standards (NCTM, 2000) propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?

2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?

3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix B

Biographical Sketches of Committee Members

JERRY P. GOLLUB (*Cochair*) is John and Barbara Bush Professor in the Natural Sciences (Physics) at Haverford College. He is a member of the National Academy of Sciences (NAS), a fellow of the American Academy of Arts and Sciences, and a recipient of a research award from the American Physical Society. His research focuses on nonlinear and nonequilibrium phenomena, including instabilities and pattern formation in fluids, chaotic dynamics and turbulence, and granular materials. He is coauthor of *Chaotic Dynamics: An Introduction*, an undergraduate textbook. Since 1981 he has also been affiliated with the University of Pennsylvania, where he is a member of the graduate groups in both physics and mechanical engineering. Dr. Gollub has served as Provost of Haverford College and currently chairs its Physics Department. He has served on the advisory board of the National Science Resources Center, curriculum developers for schools, and has been a member of the National Research Council's (NRC) Commission on Physical Sciences, Mathematics, and Applications. He received his Ph.D. in experimental condensed matter physics from Harvard University.

PHILIP C. CURTIS, JR. (*Cochair*) is Professor of Mathematics Emeritus at the University of California at Los Angeles, where he has taught mathematics since 1955. He has served as vice chair and chair of the University of California Board of Admissions and Relations with Schools, chairman of the faculty of the UCLA College of Letters and Science, chair of the UCLA Mathematics Department, director of the UCLA Teaching Interns Program in Mathematics, and chair of the Committee for Mathematics and Science Scholars. Dr. Curtis has served on the NRC's Study Group on Guidelines for Mathematics Assessment. He received his Ph.D. from Yale University.

CAMILLA BENBOW is Dean of the Peabody College of Education and Human Development at Vanderbilt University. Her field is educational psychology, and her research has focused on the optimal development of talent,

strategies for teaching gifted and talented students, and academic achievement in math and science. She has also served as director of the Iowa Talent Search Program and as codirector for the Study of Mathematically Precocious Youth at The Johns Hopkins University, at Iowa State University, and now at Vanderbilt. In addition, she has directed other studies and programs for gifted and talented and mathematically precocious youth. Dr. Benbow received her M.A. in psychology and her M.S. and Ph.D. in education from The Johns Hopkins University.

HILDA BORKO is a professor in the School of Education at the University of Colorado at Boulder. Her field is educational psychology, and her research has focused on teacher cognition and teacher learning. Specific interests have included teachers' understanding of education reform, teacher preparation and professional development, and instruction and assessment. Dr. Borko has served on numerous professional committees. In addition to her service editing and reviewing for professional publications, she has published extensively on many aspects of teacher preparation and learning to teach. She received her M.A. in the philosophy of education and her Ph.D. in educational psychology from the University of California at Los Angeles.

WANDA BUSSEY is Mathematics Department chair and teacher of International Baccalaureate Higher Level Mathematics at Rufus King High School in Milwaukee, Wisconsin, where she has taught since 1979. She assisted the school in instituting and developing its IB program and is an IB Senior Teacher. She has also served as an assistant examiner for the IB Examinations Office. Her work in that capacity has entailed curriculum development, modeling of her school's program for others, and presentations at IB workshops around the country. Ms. Bussey has taught calculus at Marquette University and at the University of Wisconsin and is a recipient of the Tandy Technology Scholar Teacher of the Year award. She received her M.S. in mathematics from the University of Wisconsin, Milwaukee.

GLENN A. CROSBY is Professor of Chemistry and Materials Science Emeritus at Washington State University. His research has focused on investigation of the electronic excited states of metal complexes; design of materials for solar energy storage; investigation of photochemical reactions; and design of semiconducting, photoconducting, and paramagnetic solids. Dr. Crosby has received numerous awards for his teaching and has been active in the development of science programs for high school students and professional development programs for teachers. He received his Ph.D. in physical chemistry from the University of Washington.

JOHN A. DOSSEY is Distinguished University Professor of Mathematics Emeritus at Illinois State University. His research interests include evaluation in mathematics education, international mathematics education, and assessment in mathematics education. Dr. Dossey served as president of the National Council of Teachers of Mathematics during the writing of that organization's standards for school mathematics. He has also chaired the Conference Board of the Mathematical Sciences and the U.S. Commission on Mathematical Instruction at the NRC, as well as the College Board's Mathematical Sciences Advisory Committee. He has served on the NRC's Board on International Comparative Studies in Education, which has devoted considerable attention to the Third International Mathematics and Science Study. Dr. Dossey received his Ph.D. in mathematics education from the University of Illinois, Urbana-Champaign.

DAVID ELY is a teacher of Advanced Placement Biology at Champlain Valley Union High School in Hinesburg, Vermont. He has been an exam reader for the AP biology program for 7 years and has been involved in the development of Vermont's science framework and assessments. Mr. Ely has been named National Science Teachers Association/Shell Outstanding National Science Teacher of the Year and has received the Distinguished Teacher Award from the White House Commission on Scholars, as well as many other teaching awards. He received his B.A. and M.A.T. in zoology from the University of Vermont.

DEBORAH HUGHES HALLETT is a professor of mathematics at the University of Arizona; from 1991 to 1998 she was a professor of Practice in the Teaching of Mathematics at Harvard University. She was a principal investigator for the National Science Foundation (NSF)-funded Bridge Calculus Consortium. She has served on committees for the Graduate Record Examination and the Massachusetts state mathematics framework review process, and on the Mathematics and Science Teacher Education Program (MASTEP) Advisory Board, an NSF-funded program to improve teacher training in California. Dr. Hughes Hallett served on the NRC's Committee on Information Technology in Undergraduate Education. A Fulbright Scholar, she received M.A. degrees from both Harvard University and the University of Cambridge, England.

JOHN K. HAYNES is David Packard Professor of Science and chair of the Biology Department at Morehouse College. He is also an adjunct professor of Physiology at Brown University. He has served on a number of panels concerned with education issues, including that for the Undergraduate Bio-

logical Sciences Education Program of the Howard Hughes Medical Institute. Dr. Haynes served on the NRC's Committee on Undergraduate Science Education and has been a councilor in the Biology Division for the Council on Undergraduate Research. He serves as chair of the Minorities Affairs Committee of the American Society for Cell Biology. He received his Ph.D. in developmental biology from Brown University.

VALERIE E. LEE is a professor of education at the University of Michigan. Her research has focused on school size and the development of more personalized social relations in schools. She has also studied high school restructuring, factors that influence achievement, ability tracking, and academic behaviors. Some of her research has targeted the development of high-achieving minority students and gender differences in mathematics and science achievement. Dr. Lee received her Ed.D. from Harvard University.

STEPHANIE PACE MARSHALL is founding president of the Illinois Mathematics and Science Academy and has served in that capacity since 1986. A former Superintendent of Schools in Batavia, Illinois, she has also served as president of the Association for Supervision and Curriculum Development International, and was founding president of the National Consortium for Specialized Schools of Mathematics, Science, and Technology. Dr. Marshall received her M.A. in curriculum and philosophy from the University of Chicago and her Ph.D. in educational administration and industrial relations from Loyola University in Chicago.

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Appendix C

Statement of Task

The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

I. LEARNING

1. What does research tell us about how high-school aged students learn science and mathematics? Does this process differ significantly for the most advanced students?
2. To what extent do the AP and IB or other programs for advanced students incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instruction, and assessments? How could research on cognition and learning be used to improve these programs?
3. What is the impact of student assessment on the learning process in mathematics and science? How could student assessment be used to improve student learning in advanced courses?

II. TEACHING

1. What does research tell us about effective instructional practices for high-school aged students generally, and for advanced students in particular?

2. To what extent do AP and IB programs encourage teaching practices that are consistent with current research on effective instructional practices? Are there alternative programs that are more effective in this regard?

3. How do final assessments generally, and AP and IB assessments in particular, influence instructional practices?

4. What academic qualifications are needed to teach advanced science and mathematics courses, and how are teachers actually selected?

5. What does research tell us about how teachers learn to teach, and about effective professional development practices? What does this research imply about the nature and quality of professional development opportunities for teachers offered by programs of advanced study, including AP and IB?

III. CURRICULUM AND STANDARDS

1. To what extent do the IB and AP programs reflect the best in current thinking about content and curriculum for teaching mathematics and science? Are any alternative programs superior in some respects?

2. How do the content and performance standards of the AP and IB programs compare with one another and with the NRC *National Science Education Standards* or those of the Mathematical Association of America or the National Council of Teachers of Mathematics?

3. To what extent do programs such as AP and IB help to promote and elevate academic standards in high schools, both within individual subject areas and generally?

How do AP and IB standards compare with those used by other programs for advanced study in science and mathematics? How do AP and IB standards compare with those of other technologically advanced nations?

IV. CONTEXT AND CONSEQUENCES

1. How do the beliefs and values about the purpose of secondary schooling held by the American public influence what courses high schools offer, access to these courses, how the courses are taught, and what students learn in them, particularly in advanced courses in mathematics and science?

2. What constraints do the culture and resources of American high schools typically place on programs for advanced study?

3. How can the goal of equitable and broad access to programs for advanced study best be pursued?

4. How does the interface with higher education affect programs for advanced study in the secondary schools?

Index

A

- AAAS. *See* American Association for the Advancement of Science
- Ability grouping in mathematics, in preparing for advanced study in middle school, 39-40
- Academic competitions, for enrichment, 115
- Access to advanced study, 191-192
 - implementing prerequisites, 192
 - inequalities in, 4
 - limiting students' access to AP and IB, 191-192
 - recommendations, 12, 198-199
- Access to Excellence*, 65
- Accountability
 - demands for, 19, 30n
 - role and influence of, 31-32
- ACT. *See* American College Testing Program
- Admissions. *See* College admission decisions
- Advanced critical and creative thinking skills, in high-ability learners, 132
- Advanced Placement (AP) program, 1, 20-21, 64-82. *See also* AP and IB programs
 - assessment, 75-79
 - Calculus Development Committee, 67
 - college credit and placement in, 192-194
 - course descriptions and teacher's guides, 72-74
 - curriculum, 66-71
 - instruction, 71-75
 - professional development, 79-82
 - role in college admission decisions, 55-57
 - Technical Manual, 181
 - using for placement or exemption from required courses, 58-59
- Advanced study
 - components of, 3-4
 - connections between advanced study and higher education, 51-63
 - context of, 2-5, 28-63
 - defining, 1n, 22
 - disparities in opportunities to pursue and succeed in, 47-51
 - educational context, 36-47
 - financing programs at the local level, 33
 - as a link between high school and college, 52-57
 - opportunities and approaches to, 103-116
 - overview of, 5-6, 22-23
 - policy context, 29-36
 - primary goal of, 1n
 - role in college admission decisions, 53-57
 - secondary-postsecondary interface, 4-5
 - unequal access to, 4
 - urgent need to transform, 153
- AERA. *See* American Educational Research Association
- AFT. *See* American Federation of Teachers
- Alternative means of problem solving, by high-ability learners, 131
- Alternatives for providing college-level learning in high school, 103-113
 - collaborative programs, 104-105
 - college courses taught in high schools, 105
 - college-sponsored enrichment programs, 108
 - concurrent enrollment, 106-108
 - curricular and instructional approaches for enrichment, 115-116
 - distance learning, 109-110

- dual-enrollment, 105-106
 - overview of, 6
 - recommendations, 14, 202
 - specialized schools, 108-109
 - web-based courses, 111-113
 - American Association for the Advancement of Science (AAAS), 3, 31, 43, 177
 - Project 2061, 161
 - American College Testing (ACT) Program, 53
 - American Educational Research Association (AERA), 180-182, 186
 - American Federation of Teachers (AFT), 36, 42
 - American Psychological Association (APA), 180-182, 186
 - American Youth Policy Forum, 42
 - AP. *See* Advanced Placement program
 - AP and IB effects on schools, 187-188
 - evaluating school quality by the numbers, 188
 - ranking schools by the number of AP or IB tests taken, 187-188
 - AP and IB programs, 8-11, 154-184, 259-260
 - assessment, 10, 180-183
 - context and consequences, 260
 - differences among learners, 9, 166-168
 - examination grades and the admission process, 57
 - instruction, 10, 178-180
 - learning, 259
 - learning communities, 9, 170-172
 - learning in context, 172-174
 - limited access to, 191-192
 - metacognition, 8, 164-166
 - motivation, 9, 168-170
 - principled conceptual knowledge, 8, 156-159
 - prior knowledge, 8, 160-164
 - professional development, 10-11, 183-184
 - situated learning, 9
 - teaching, 259-260
 - APA. *See* American Psychological Association
 - APEX Learning Systems, 111n, 112
 - Assessment, 7-8, 20
 - findings, 235, 243, 247
 - formative, 163-164
 - internal, 92
 - recommendations, 13, 201, 237-238, 245, 249
 - for understanding, 8, 144, 147
 - Assessment in AP and IB programs, 10, 180-183
 - consequential validity of AP and IB assessments, 182-183
 - examination design and development, 180
 - support for inferences drawn from assessment results, 181-182
 - Assessment in the AP program, 75-79
 - College Board determinations about AP examinations and their purpose, 78-79
 - College Board recommendations about granting college credit for AP examinations, 77
 - developing examinations, 75-77
 - reporting examinations, 78
 - scoring examinations, 77
 - Assessment in the educational system, 141-146
 - reliability, validity, and fairness, 143
 - Assessment in the IB programme, 94-100
 - criteria for IB experimental sciences courses, 90
 - developing assessments, 95-96
 - reporting assessments, 98-100
 - scoring assessments, 96-98
 - Association of American Colleges and Universities, 106
 - “Average” defined, 177
- ## B
- Benchmarks for Science Literacy*, 31
 - Biology panel, 233-238
 - principal findings, 233-235
 - recommendations, 236-238
 - Boredom, of high-ability learners, 131-132
 - Boston University, Program in Mathematics for Young Scientists, 114
 - Breadth versus depth, of principled conceptual knowledge, 156-157
 - Bush, George W., 21
- ## C
- Calculus
 - findings of the mathematics panel on impact of, 248

- history of AP reform, 178n
- Calculus Development Committee, 67
- Calculus for a New Century*, 169n
- Campbell, Paul, 85n, 195
- Capacity for learning, underestimated in
 - high-ability learners, 132
- Caperton, Gasper, 72
- Carnegie classifications, for ranking
 - undergraduate institutions, 54
- Carson, Eugene, 182
- CCSSO. *See* Council of Chief State School Officers
- CEEB. *See* College Entrance Examination Board
- Center for Talented Youth, 108n
- Certification of teachers, 35
- CFAPP. *See* Commission on the Future of the Advanced Placement Program
- Changes in the AP and IB programs, 14-15, 203-205
 - College Board and IBO assessment practice, 14, 203-204
 - College Board and IBO developing research in the implementation of their programs, 15, 204-205
 - College Board and IBO providing assistance to schools, 15, 204
 - College Board and IBO providing guidance in the use of examination scores, 15, 204
 - College Board and IBO responsibility for appropriate instructional approaches, 14, 204
 - College Board exercising quality control over the AP trademark, 14-15, 204
 - College Board practice in designing AP courses, 14, 203
 - recommendations, 14-15, 203-205
- Charter schools, 109
- Chemistry panel, 239-241
 - principal findings, 239
 - recommendations, 239-241
- Class Struggle: What's Wrong (and Right) with America's Best Public High Schools*, 185
- Class.com, 111n
- CLEP. *See* College-Level Examination Program
- Clinton, William, 111n
- Collaborative programs, providing college-level learning in high school, 104-105
- College admission decisions
 - process of, 53-55
 - recommendations, 203
 - role of advanced study in, 53-57
 - role of AP and IB in, 55-57
- College and university scientists and mathematicians, modifying their introductory courses, 14, 203
- College Board, 1, 9-10, 15n, 18n
 - assessment practice, 14, 203-204
 - Commission on the Future of the Advanced Placement Program, 22, 65, 81-82, 154
 - determining whether AP examinations accomplish their purpose, 78-79
 - developing research in the implementation of its programs, 15, 204-205
 - Equity 2000, 168
 - exercising quality control over the AP trademark, 14-15, 204
 - granting students college credit for AP examinations, 77
 - membership in, 20n
 - Pathways Programs, 168
 - practice in designing AP courses, 14, 53, 203
 - providing assistance to schools, 15, 204
 - providing guidance in the use of examination scores, 15, 61, 204
 - recommendations concerning assessment practice, 14, 203-204
 - recommendations concerning assistance to schools, 15, 204
 - recommendations concerning guidance in the use of examination scores, 15, 204
 - recommendations concerning research in the implementation of their programs, 15, 204-205
 - recommendations concerning responsibility for appropriate instructional approaches, 14, 204
 - responsibility for appropriate instructional approaches, 14, 204
 - support from the Educational Testing Service, 64
 - Vertical Teams initiative, 38n, 82n, 168
- College courses taught in high school, 105
- College credit and placement, 192-196
 - AP program, 192-194

- based on advanced study, 58-61
- denial of credit or placement, 60-61
- IB program, 194-196
- institutional decisions, 60
- reducing time to degree, 58
- using AP and IB for placement or exemption from required courses, 58-59
- College Entrance Examination Board (CEEB), 18, 20, 157, 190. *See also* College Board
- College-high school interface. *See* Secondary-postsecondary interface
- College-Level Examination Program (CLEP), 103n
- College-sponsored enrichment programs, in high schools, 108
- Commission on the Future of the Advanced Placement Program (CFAPP), 22, 65, 81-82, 154
- Committee on Education Finance, 33n
- Components of advanced study, 3-4
 - coordination, 3
 - curricular differentiation, 3
 - sequencing, 3
 - standards, 3-4
 - students, 4
 - teachers, 3
- Computer-based multimedia courses, 112-113
- Concept maps, 124-125
 - in assessment, 144
- Conceptual knowledge, principled, 118-120
- Conceptual learning, in principled conceptual knowledge, 158-159
- Concurrent enrollment, providing college-level learning in high school, 106-108
- Connections among disparate bodies of knowledge, high-ability learners' capacity to make easily, 132-133
- Consequential validity, of AP and IB assessments, 182-183
- "Constrained" curriculum model, 41
- Content
 - of AP courses, 67-68
 - of IB courses, 87-89
- Content panels, 250-252
 - biology panel, 233-238
 - charge to, 250
 - chemistry panel, 239-241
 - curricular and conceptual frameworks for learning, 250-251
 - emphases, 252
 - mathematics panel, 246-249
 - physics panel, 242-245
 - preparation for further study, 252
 - role of assessment, 251
 - teaching, 251
- Coordination
 - of advanced study, 3
 - of courses, 161-162
- Core curriculum approach, 41
- Council of Chief State School Officers (CCSSO), 33, 37, 44
- Course content, evolution of, 232
- Creative thinking skills, high-ability learners advanced in, 132
- Critical thinking skills, high-ability learners advanced in, 132
- Curricular differentiation, in advanced study, 3
- Curriculum, 7-8
 - in the educational system, 135-137
 - findings, 233-234, 242, 246
 - preparing for advanced study in high school, 40-42
 - recommendations, 13, 199-200, 236-237, 239-240, 244-245
 - for understanding, 135, 138
- Curriculum compression, and quality control for AP and IB, 189-190
- Curriculum in AP and IB programs, 9-10, 176-178, 260
 - curriculum development, 177-178
 - depth versus breadth, 176-177
 - variability, 178
- Curriculum in the AP program, 66-71
 - content of AP courses, 67-68
 - development of AP courses, 66-67
 - guidance provided to teachers about curriculum development, 69-71
 - laboratory requirement for AP science courses, 68-69
- Curriculum in the IB programme, 86-91
 - assessment criteria for experimental sciences courses, 90
 - content of IB courses, 87-89
 - development of IB courses, 87
 - expectations of students to meet assessment criteria for experimental sciences courses, 91
 - laboratory requirement for IB experimental sciences courses, 89-91

D

- Day academies, 109
- Denial of credit or placement, 60-61
- Design of educational systems, 134-153
 - assessment, 141-146
 - curriculum, 135-137
 - from framework to advanced study programs, 152-153
 - instruction, 137-141
 - professional development, 146-152
- Design of programs
 - assessment, 7-8
 - based on research on learning and pedagogy, 6-8
 - curriculum, 7-8
 - instruction, 7-8
 - professional development, 7-8
 - seven principles of human learning, 6-7
- Development
 - of AP courses, 66-67
 - of AP examinations, 75-77
 - by high-ability learners of greater expectations when working with others of similar ability, 133
 - of IB assessments, 95-96
 - of IB courses, 87
- Differences among learners, 9, 166-168
 - a principle of human learning, 123, 126
 - using differences among learners in assessment, 166-168
- Disparate bodies of knowledge, high-ability learners making connections easily among, 132-133
- Disparities in opportunities to pursue and succeed in advanced study, 47-51
 - in outcome, 49-51
 - in participation, 48-49
 - racial/ethnic disparities in advanced placement scores by subject, 50
 - school racial/ethnic disparities in mathematics and science offerings, 49-51
- Distance learning, providing college-level learning in high school, 109-110
- Dual-enrollment, providing college-level learning in high school, 105-106

E

- Early mastery of high school math and science, by high-ability learners, 131
- Early Outreach Program, 114
- Economic forces, 20
- Education Program for Gifted Youth (EPGY), 113
- Education Week*, 32, 35n, 42, 44
- Educational context of advanced study, 36-47
 - preparing for advanced study in high school, 40-47
 - preparing for advanced study in middle school, 36-40
- Educational Testing Service (ETS), 64, 76
- End-of-course examinations, 145
- Energy transfer theme, applications to three main subject areas, 70-71
- Enrichment activities for advanced study, 113-116
 - academic and research competitions, 115
 - alternative curricular and instructional approaches, 115-116
 - internships, 114
 - mentorships, 114
- Enrollment in an advanced course, 169
- EPGY. *See* Education Program for Gifted Youth
- Equity, 182, 191-192
- Equity 2000, 168
- ETS. *See* Educational Testing Service
- Examinations
 - design and development, 180
 - end-of-course, 145
 - in principled conceptual knowledge, 158-159
 - and quality control for AP and IB, 190
 - recommendations, 231-232
- "Excellence," 177
- Exemption from required courses, using AP and IB for, 58-59
- Expectations of students, to meet assessment criteria for IB experimental sciences courses, 91

F

- Fairness, 143
- Fast Response Survey System, 34

Financing advanced study programs at the local level, 33
Formative assessment, misconceptions about, 163-164
Funding agencies, recommendations, 202

G

Goal 3, 30
Goal of advanced study, primary, 12, 197-198
Governors' schools, 109
Grade-point average (GPA) system, 40n
Guidance provided to teachers by AP, about curriculum development, 69-71
Guide for the Recommended Laboratory Program for Advanced Placement Chemistry, A, 69, 73

H

High-ability learners, 130-133
 advanced in their critical and creative thinking skills, 132
 developing greater expectations and engaging in higher-level processing when working with others of similar ability, 133
 displaying exceptionally rich knowledge base in their specific talent domain, 130
 having the capacity to make connections easily among disparate bodies of knowledge, 132-133
 having the propensity to be profoundly influenced by a single mentor, 133
 having their capacity for learning underestimated, and thus become underdeveloped, 132
 learning at a more rapid rate than other students, 131
 often able to solve problems by alternate means, without understanding the underlying concepts, 131
 often having mastered high school math and science before formally taking the course, 131
 often losing motivation to achieve because of boredom, 131-132

 picking up informally much of the content knowledge taught in school, 130-131
 preferring unstructured problems in which the talk is less well defined, 132
High-level processing, high-ability learners engaging in when working with others of similar ability, 133
High-quality instruction, promotion of, 179-180
High school-college interface. *See* Secondary-postsecondary interface
High school mathematics and science
 early mastery by high-ability learners, 131
 preparing for advanced study, 42-44
High school preparation for advanced study, 40-47
 curriculum, 40-42
 students, 46-47
 teaching challenges, 44-46
High stakes for AP and IB, 185-188
 effects on schools, 187-188
 effects on students, 186
 effects on teachers, 187
 effects on teaching and learning, 186-187
Higher-level mathematics and science courses, percentage of all high school students taking, 43-44
How People Learn: Brain, Mind, Experience, and School, 18, 116, 118n
Human learning, seven principles of, 118-129

I

IB. *See* International Baccalaureate Programme
IB Diploma Programme Guide, 87
IBCA. *See* International Baccalaureate Curriculum and Assessment Centre
IBNA. *See* International Baccalaureate of North America
IBO. *See* International Baccalaureate Organisation
Inferences drawn from assessment results, support for, 181-182
Information technology, 20
 evolution of, 232

- Institutional decisions, 60
awarding credit and advanced placement
for courses beyond the introductory
college level, 14, 202-203
- Instruction, 7-8
in the educational system, 137-141
findings, 234, 242-243, 246
recommendations, 13, 200, 240, 245, 249
for understanding, 7, 139, 142
- Instruction in AP and IB programs, 10, 178-180
assigning worthwhile tasks, 179
promotion of high-quality instruction,
179-180
- Instruction in the AP program, 71-75
AP course descriptions and teacher's
guides, 72-74
messages about instruction conveyed by
AP examinations, 74-75
- Instruction in the IB programme, 92-94
IB programme guides and teaching
notes, 92-93
messages about instruction conveyed by
IB examinations, 93-94
"predicted grades," 57n, 94-95
- Internal assessment, 92
- International Baccalaureate Curriculum and
Assessment Centre (IBCA), 87, 98
- International Baccalaureate of North America
(IBNA), 85-86
- International Baccalaureate Organisation
(IBO), 1, 9, 21, 83
assessment practice, 14, 203-204
developing research in the
implementation of its programs, 15,
204-205
- Middle Years Programme, 168
providing assistance to schools, 15, 204
providing guidance in the use of
examination scores, 15, 204
recommendations concerning assessment
practice, 14, 203-204
recommendations concerning assistance
to schools, 15, 204
recommendations concerning guidance
in the use of examination scores, 15,
204
recommendations concerning research in
the implementation of their programs,
15, 204-205
- recommendations concerning
responsibility for appropriate
instructional approaches, 14, 204
responsibility for appropriate
instructional approaches, 14, 204
- International Baccalaureate (IB) Programme,
1, 83-102. *See also* AP and IB
programs
assessment, 94-100
college credit and placement in, 194-196
curriculum, 86-91
guides and teaching notes, 92-93
instruction, 92-94
professional development, 100-102
role in college admission decisions, 55-57
using for placement or exemption from
required courses, 58-59
- Internships, for enrichment, 114
- J**
- Johns Hopkins University, The, Center for
Talented Youth, 108n
- Jones, Lee, 104n
- K**
- Knowledge
"presumed," 160n
principled conceptual, 118-120
prior, 120-122
- L**
- Laboratory requirements
for AP science courses, 68-69
for IB experimental sciences courses, 89-91
- Learners. *See also* High-ability learners
differences among, 123, 126
- Learning
capacity of high-ability learners
underestimated, 132
in context, 172-174
effects of AP and IB on, 186-187
by high-ability learners, 130-131
informal, of content taught in school,
130-131

- rapid, 131
 - seven principles of human, 118-129
 - situated, 127-128
 - with understanding, 119
 - Learning communities, 9, 170-172
 - a principle of human learning, 128-129
 - Learning principles, recommendations, 13, 199
 - Learning research, analysis of AP and IB programs based on, 8-9, 154-175
 - Learning with understanding, 7-8, 117-133
 - characteristic of high-ability learners, 130-133
 - concept maps, 124-125
 - seven principles of human learning, 118-129
 - Legislative initiatives, 30. *See also individual laws*
 - recommendations, 203
 - Limited access to AP and IB, 191-192
 - Links between advanced study and higher education, 51-63
 - admission decisions, 53-55
 - advanced study as a link between high school and college, 52-57
 - AP and IB examination grades and the admission process, 57
 - college credit and placement based on advanced study, 58-61
 - role of advanced study in college admission decisions, 53-57
 - role of AP and IB in admission process, 55-57
 - secondary-postsecondary interface
 - coordination and articulation, 51-52
 - variability of credit and placement decisions, 61-63
 - Low motivation to achieve, of high-ability learners, 131-132
- M**
- Magnet schools, 109
 - Mathematical Association of America, 169n, 260
 - Mathematics. *See also* Calculus
 - changes in, 19
 - Mathematics and science courses
 - hierarchical nature of, 19-20
 - high school, 42-44, 131
 - higher-level, 43-44
 - middle school, 37-38
 - school racial/ethnic disparities in, 49-51
 - Mathematics courses, ability grouping in, 39-40
 - Mathematics panel, 246-249
 - principal findings, 246-248
 - recommendations, 248-249
 - Mentorships
 - for enrichment, 114
 - high-ability learners' propensity to be influenced by, 133
 - Messages about instruction
 - as conveyed by AP examinations, 74-75
 - as conveyed by IB examinations, 93-94
 - Metacognition, 8, 164-166
 - a principle of human learning, 122-123
 - Middle school mathematics and science, 37-38
 - Middle school preparation for advanced study, 36-40
 - ability grouping in mathematics, 39-40
 - teaching challenges, 38
 - Misconceptions, 136
 - and formative assessment, 163-164
 - Moderation Report on the Internal Assessment*, 100
 - Motivation, 9, 168-170
 - believing in the possibility of success, 168
 - deciding to enroll in an advanced course, 169
 - the final examination, 170
 - investing effort for success, 169-170
 - low in high-ability learners, 131-132
 - a principle of human learning, 126-127
 - Multimedia courses, computer-based, 112-113
- N**
- NAEP. *See* National Assessment of Educational Progress
 - NASSP. *See* National Association of Secondary School Principals
 - Nation at Risk, A*, 29
 - National Aeronautics and Space Administration, 113-114
 - National Assessment of Educational Progress (NAEP), 29

- National Association of Secondary School Principals (NASPP), 42
- National Board for Professional Teaching Standards (NBPTS), 140, 200
- National Center for Education Statistics (NCES), 18, 28, 43n
- National Coalition for Parent Involvement in Education, 51n
- National Commission on Excellence in Education, 29
- National Commission on Mathematics and Science Teaching for the 21st Century, 150, 184, 240
- National Commission on the High School Senior Year (NCHSSY), 42
- National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology, 109
- National Council of Teachers of Mathematics (NCTM), 3, 32, 43, 169n, 177, 200, 260
- National Council on Measurement in Education (NCME), 180-182, 186
- National Council on the Evaluation of Foreign Student Credentials, 194
- National Education Goals Panel, 30
- National Institute on Student Achievement, Curriculum, and Assessment, 45
- National Institutes of Health, 113-114
- National Research Council (NRC), 1, 3, 17, 31, 43, 117
- Committee on Education Finance, 33n
- National Science Education Standards* (NSES), 31, 162, 200, 230-231, 234, 237, 240, 244, 260
- National Science Foundation, 18
- National Science Teachers Association (NSTA), 45-46
- National Task Force on Minority High Achievement, 15n, 204n
- NBPTS. *See* National Board for Professional Teaching Standards
- NCES. *See* National Center for Education Statistics
- NCHSSY. *See* National Commission on the High School Senior Year
- NCME. *See* National Council on Measurement in Education
- NCTM. *See* National Council of Teachers of Mathematics
- NetCourses, 112
- Newsweek*, 185
- No Child Left Behind* Act, 32
- NRC. *See* National Research Council
- NSES. *See* *National Science Education Standards*
- NSTA. *See* National Science Teachers Association
- O**
- Office of Educational Research and Improvement (OERI), 41
- Ohio State University, 114
- Online courses, and quality control for AP and IB, 190-191
- Organization of complex content, in principled conceptual knowledge, 157-158
- Outcome of advanced study, disparities in, 49-51
- Overview
- of panel findings and recommendations, 229
 - of the programs, 5-6, 20-22
- P**
- Paige, Rod, 30
- Participation in advanced study, disparities in, 48-49
- Pathways Programs, 168
- Physics panel, 242-245
- principal findings, 242-243
 - recommendations, 243-245
- Policy context of advanced study, 29-36
- financing advanced study programs at the local level, 33
 - role and influence of standards and accountability, 31-32
 - teacher qualifications, certification, and challenges, 33-36
- Practical Scheme of Work (PSOW), 90-91
- "Predicted grades" in the IB programme, 57n, 94
- Preparation and credentials
- of AP teachers, 79
 - of IB teachers, 100-101
- Preparation for advanced study
- in high school, 40-47
 - in middle school, 36-40

- Prerequisites
 - for AP and IB, 192
 - and prior knowledge, 160-161
 - “Presumed” knowledge, 160n
 - Principled conceptual knowledge, 8, 156-159
 - breadth versus depth, 156-157
 - examinations and conceptual learning, 158-159
 - organizing complex content, 157-158
 - a principle of human learning, 118-120
 - Principles and Standards for School Mathematics*, 230
 - Principles of human learning, 118-129
 - differences among learners, 123, 126
 - learning communities, 128-129
 - metacognition, 122-123
 - motivation, 126-127
 - principled conceptual knowledge, 118-120
 - prior knowledge, 120-122
 - situated learning, 127-128
 - Prior knowledge, 8, 160-164
 - coordination of courses, 161-162
 - implications for instruction, 162-163
 - misconceptions and formative assessment, 163-164
 - prerequisites, 160-161
 - a principle of human learning, 120-122
 - Professional associations, recommendations, 202
 - Professional development, 7-8
 - in the educational system, 146-152
 - effective, 149, 152
 - findings, 234, 246
 - recommendations, 240-241, 245, 249
 - Professional development in the AP program, 79-82
 - experiences of AP teachers, 79-82
 - preparation and credentials of AP teachers, 79
 - Professional development in the IB programme, 100-102
 - experiences of IB teachers, 101-102
 - preparation and credentials of IB teachers, 100-101
 - Program design, based on research on learning and pedagogy, 6-8
 - Program developers, recommendations, 199-200, 203
 - Program in Mathematics for Young Scientists, 114
 - Program staff, recommendations, 201
 - Project Advance, 105n
 - Promising Practices, 30
 - Promotion of high-quality instruction, 179-180
 - PSOW. *See* Practical Scheme of Work
- ## Q
- Qualified teachers and professional development, recommendations, 13-14, 201-202
 - Quality control for AP and IB, 188-191
 - curriculum compression, 189-190
 - online courses, 190-191
 - participation in examinations, 190
 - standards and regulation of courses, 189
- ## R
- Racial/ethnic disparities
 - in advanced placement scores, by subject, 50
 - in mathematics and science offerings, school-level, 49-51
 - Recommendations, 12-15, 197
 - access and equity, 12, 198-199
 - alternative programs, 14, 202
 - assessment, 13, 201, 237-238, 245, 249
 - from the biology panel, 236-238
 - for changes in the AP and IB programs, 14-15, 203-205
 - from the chemistry panel, 239-241
 - college admission decisions, 203
 - curriculum, 13, 199-200, 236-237, 239-240, 244-245
 - examinations, 231-232
 - funding agencies, 202
 - instruction, 13, 200, 240, 245, 249
 - interpretation of, 230-231
 - learning principles, 13, 199
 - from the mathematics panel, 248-249
 - from the physics panel, 243-245
 - for the primary goal of advanced study, 12, 197-198
 - professional associations, 202
 - professional development, 240-241, 245, 249
 - program developers, 199-200, 203
 - program staff, 201

- qualified teachers and professional development, 13-14, 201-202
- review of, 230-231
- school administrators, 200
- secondary-postsecondary interface, 14, 202-203, 232, 241
- student preparation, 232, 244, 248-249
- teacher preparation, 232
- Reduction of time to degree, 58
- Regulation of courses, and quality control for AP and IB, 189
- Reliability, 143
- Reporting
 - of AP examinations, 78
 - of IB assessments, 98-100
- Required courses, using AP and IB for placement or exemption from, 58-59
- Research competitions, for enrichment, 115
- Residential academies, 109
- Rich knowledge base, high-ability learners displaying, 130
- Riley, Richard, 21, 29, 30n, 111n
- Ross, Arnold, 114

- S**
- Salaries, trends in teacher, 36
- School administrators, recommendations, 200
- School profiles, 54
- School quality
 - effects of AP and IB on, 187-188
 - evaluating by the numbers, 188
 - ranking by the number of AP or IB tests taken, 187-188
- Schools-within-a-school, 109
- Science. *See also* Mathematics and science courses; *individual disciplines*
changes in, 19
- Science for All Americans*, 31
- Scoring
 - of AP examinations, 77
 - of IB assessments, 96-98
- Secondary-postsecondary interface
 - in advanced study, 4-5
 - college and university scientists and mathematicians modifying their introductory courses, 14, 203
 - coordination and articulation, 51-52
 - findings, 235
 - institutions awarding credit and advanced placement for courses beyond the introductory college level, 14, 202-203
 - recommendations, 14, 202-203, 232, 241
- Sequencing, of advanced study, 3
- Seven principles of human learning, 118-129
 - differences among learners, 123, 126
 - learning communities, 128-129
 - metacognition, 122-123
 - motivation, 126-127
 - principled conceptual knowledge, 118-120
 - prior knowledge, 120-122
 - situated learning, 127-128
- SHARP. *See* Summer High School Apprenticeship Research Program
- Shortages of teachers, 20, 35-36
- Situated learning, 9
 - a principle of human learning, 127-128
- Solving problems by alternate means, by high-ability learners, 131
- Southern Regional Education Board, 42
- Specialized schools, providing college-level learning in high school, 108-109
- Standards
 - for advanced study, 3-4
 - and quality control for AP and IB, 189
 - role and influence of, 31-32
- Standards for Educational and Psychological Testing, 186
- Stanford University, Education Program for Gifted Youth, 113
- State Higher Education Executive Officers, 106-107
- Student clientele for advanced study, 23-24
- Students
 - in advanced study, 4
 - effects of AP and IB on, 186
 - preparing for advanced study in high school, 46-47
 - recommendations for preparation of, 232, 244, 248-249
- Success
 - believing in the possibility of, 168
 - investing effort for, 169-170
- Summer High School Apprenticeship Research Program (SHARP), 108n
- Survey of mathematics and biology departments, regarding credit and placement decisions, 61-63

Syracuse University, Project Advance, 105n

T

Tasks, assigning worthwhile, 179

Teacher preparation. *See also* Professional development
recommendations, 232

Teachers

- of advanced study, 3
- certification of, 35
- effects of AP and IB on, 186-187
- in high school, 44-46
- in middle school, 38
- qualifications of, 33-36
- shortages of, 20, 35-36
- trends in salaries of, 36

Teachers Learning Conference, 112

Teaching. *See* Instruction

Tech Prep, 106

Televised courses, 110

Top 10 Percent Law, 53

Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology, 241

2+2 programs, 106

U

Understanding, learning with, 119

Unequal access, to advanced study, 4

University of California, Early Outreach Program, 114

Unstructured problems, preference of high-ability learners for, 132

U.S. Department of Education, 18, 21, 29-30, 46

Uses, misuses, and unintended

consequences of AP and IB, 11-12, 185-196

access and equity, 191-192

college credit and placement, 192-196

high stakes, 185-188

quality control, 188-191

V

Vade Mecum: Procedures Manual for IB Coordinators and Teachers, 89

Validity, 76n, 78, 143, 182

consequential, of AP and IB assessments, 182-183

Variability of credit and placement decisions, 61-63, 75n

survey of mathematics and biology departments, 61-63

Vertical Teams Initiative, 38n, 82

Virginia Polytechnic Institute and State University, 182

W

Washington Post, 185

Web-based courses, 111-113

computer-based multimedia courses, 112-113

Web-Based Education Commission, 111

Weighted system of GPAs, 40n

Workshops, 80-81

Content Panel Report:

Biology

Introduction

The National Research Council's (NRC) Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed a biology panel to evaluate and compare the Advanced Placement (AP), International Baccalaureate (IB), and alternative programs for advanced study in biology with regard to content, pedagogy, and outcomes. The panel held two meetings, in April and June 2000, for the purpose of formulating answers to the questions under its charge from the parent committee (see Appendix A). The panel was chaired by a member of the parent committee, who served as liaison to the committee and consolidated the panel's findings and recommendations into this report. Panel members also included two master teachers with extensive experience in teaching high school biology and four university professors—an educator with interests in biology, two biologists with primary interests in education, and a biologist with primary interests in university-level teaching and research (for biographic sketches, see Appendix B).

The panel's conclusions are based on published evidence and the personal expertise of the panel members, as well as discussions with three consultants: an additional IB teacher who has worked extensively with the International Baccalaureate Organisation (IBO), an Educational Testing Service (ETS) consultant for the AP Biology Test Committee, and a Washington, D.C. area AP teacher. The panel drew on a variety of published sources, in particular on material from the College Board and the ETS (AP program); the IBO; and previous NRC reports, including *Fulfilling the Promise: Biology Education in the Nation's Schools* (NRC, 1990); *National Science Education Standards* (referred to below as *NSES*; NRC, 1996a) and its recent addendum *Inquiry and the National Science Education Standards* (*INSES*; NRC, 2000b); and *How People Learn: Brain, Mind, Experience, and School* (HPL; NRC, 1999) and its addendum *How People Learn: Bridging Research and Practice* (HPL2; NRC, 2000a). All panel members provided written contributions that were incorporated or excerpted in this report. The final report was reviewed

and approved by the panel members, and all the conclusions presented herein represent the panel's consensus opinions. Some of the arguments for these conclusions are based on anecdotal evidence and the experience of individual panel members, as well as published studies; we have tried to indicate clearly the nature of our sources as appropriate in the text.

As important as the panel's specific responses to the questions under its charge is its consensus opinion that major systemic changes are overdue in biology teaching, not only in high schools but also in primary schools and colleges. The AP and IB courses, while including some of the best education in the subject currently available at the secondary level, tend in general to be out of date, too broad, and too inflexible in their curricula. Moreover, they often ignore the results of recent research on science learning, pedagogy, and assessment and do not conform to the pedagogical standards of the *NSES* and *INSES*. The panel judges IB to be superior to AP in many respects, but making AP more like IB will not be enough; rather, systemic changes are required in the preparation of teachers and the teaching of biology at all levels. For example, the panel concurs with the view (NRC, 1996b, 2000b; Horn, Nunez, and Bobbitt, 2000) that many of the current shortcomings of both primary and secondary school courses stem directly from the mode of instruction experienced by high school teachers as college students. College-level introductory courses are also a substantial part of the problem because their content has been driving the AP biology curriculum in particular.

Systemic change in the teaching of mathematics was recently initiated with support from the National Science Foundation. One result has been striking changes in AP calculus instruction, demonstrating that the College Board can be responsive to reform efforts. A similar systemic initiative is under way in chemistry. The panel concludes that efforts to improve the AP and IB programs should be part of a broad initiative to reform biology teaching, as outlined in the *NSES* and the recent report of the Glenn Commission (National Commission on Mathematics and Science Teaching for the 21st Century, 2000). We are encouraged that the recent recommendations of the Commission on the Future of the Advanced Placement Program [AP Commission], (2001), discussed further below, appear likely to move the AP program in this direction.

Chapter 2 of this report defines what constitutes advanced high school biology, briefly describes the AP and IB programs, and lists some characteristics the panel would recommend for an ideal advanced biology course at the secondary level. Chapters 3 through 5 present the panel's responses to each of the questions under its charge (see Appendix A), under headings that correspond closely to the questions as posed. (Since many of the questions in the charge overlap, this format results in some inevitable redundancy.) The discussion focuses on the AP and IB programs because they are

the most widespread and influential and are the programs for which most information is available and because the panel had neither the time nor the resources necessary to address alternative programs in any depth. We evaluate the status of these two programs, compare them, and make recommendations for change. The first question in the panel's charge was, "To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?" We deal separately with the three aspects of this question in Chapters 3 and 4. Chapter 6 presents a summary and discussion of the panel's three primary and eleven secondary recommendations.

2

Advanced Study in Biology: Ideal and Reality

An advanced high school biology course should reflect the current excitement in the field of biology, where the field is now, where it is going, and the increasing extent to which it impinges on our daily lives. An advanced course should be up to date and broad enough to give students an overall picture of the field but should not attempt to be comprehensive, since doing so is impossible in a 1-year biology course at any level. Advanced study in biology should be demanding, not in the sense of covering all or even any particular areas of biology, but rather in requiring students to read and comprehend a college-level text and science articles at the level of, for example, *Scientific American*; solve problems; carry out meaningful experiments; collect, analyze, and interpret real data; write coherently about their conclusions; relate these conclusions to real-life situations and their other academic coursework; and take some responsibility for their own learning. Students should *not just acquire biological knowledge, but rather experience the process of biological science*, including generation of hypotheses from observations, design of experiments, encounters with unexpected results, collaborative learning and laboratory work with other students and teachers, and presentation of their analyses and conclusions for critical review by their peers.

To meet these expectations, both students and teachers need to be adequately prepared. Students should have taken a prior biology course or at least a prior chemistry course, preferably both. Students, unless they are exceptional, should not take advanced biology as their first high school science course; most should be juniors or seniors, so they will be mature and experienced enough to take advantage of the advanced work. Teachers should have at least a bachelor of arts or bachelor of science degree in a biological discipline, as well as the appropriate educational credentials. They should also have participated in at least one summer workshop of at least a week's duration as specific preparation in both the pedagogy and the labo-

ratory approaches for an advanced problem-oriented, student-centered biology course.

The Advanced Placement (AP) and International Baccalaureate (IB) biology courses embody the above ideal to different extents, partly because the two programs were developed to serve quite different purposes (as discussed in greater detail in the full report of the parent committee). Here we provide merely a brief summary.

The AP program was initiated in 1955 by the College Board to provide college-level courses for advanced students in high schools. A major goal of the program has been academic acceleration, providing these students with credits that can be used to place out of introductory courses and shorten the time to a college degree. Colleges use a single high-stakes assessment, the national AP examination administered by the College Board through the Educational Testing Service (ETS), as the basis for granting credit and advanced placement. The exam tests knowledge of topics taught in a small sample of college introductory biology courses (see Chapter 3), and the AP courses are designed and taught to maximize student performance on the exam; therefore, relatively few college introductory courses drive the content and pedagogy of AP courses.

The IB Programme was developed in the late 1960s to provide an international standard of secondary education primarily for the children of American, British, and European diplomats and international businesspeople, allowing these children to qualify for university admission in their home countries after undergoing schooling abroad. As with AP, a summative high-stakes exam developed by the International Baccalaureate Organisation is a major component of the assessment process that determines eligibility for university admission, but it is supplemented by several formative assessments, such as a portfolio of laboratory reports, that are also used for student evaluations. Although strong performance in IB courses is used to grant advanced placement at many universities, the focus of the IB program is on providing a high-quality, interdisciplinary university preparatory education rather than fulfilling specific university course requirements. Because it is not constrained by university curricula, IB is freer than the AP program to evolve at its own pace and in its own directions.

The AP and IB courses in biology and several other fields are clearly here to stay. They are becoming increasingly popular in American high schools among school administrators, school boards, teachers, students, and parents for many reasons, including the following:

- *For high schools and school systems*, because these programs are widely recognized and judged by national or international examinations, offering AP or IB courses can enhance a school's reputation and help in recruiting

and retaining superior students and may attract more resources from state government.

- *For teachers*, AP and IB are generally the most prestigious courses, providing the most resources, attracting the best students, and often offering opportunities for further professional development.
- *For students*, the courses provide more challenging learning opportunities as well as enhanced credentials for college admission.
- *For parents*, the courses hold the promise of not only improved chances for college admission but also college credit, with possible savings in tuition costs.

Because of their growing popularity, AP and IB courses represent an excellent opportunity to optimize learning in biology for many of the nation's best students. However, the panel believes that realizing such optimization will require substantial changes in the way the courses are organized and taught.

The panel's analysis of current AP and IB courses is based primarily on the published course outlines. We are greatly encouraged by the recent report of the AP Commission with regard to the future of AP (Commission on the Future of the Advanced Placement Program, 2001), in particular its recommendation that research leaders in the scientific disciplines and in pedagogy be engaged to ensure that current reforms and best practices are reflected in AP courses (see Chapter 3). We are well aware that some highly qualified teachers are able to transcend the current prescribed AP and IB curricula, teach state-of-the-art biology, meet many of the content and pedagogical standards set forth in the *National Science Education Standards (NSES)*, and offer courses to which some of the criticisms elaborated below do not apply. For the many teachers who are not prepared to take such initiatives, however, it is important that the curricula and teacher preparation for these courses be upgraded and assessed to ensure high minimum standards of content, laboratory experience, and pedagogy, with the eventual goal of meeting the *NSES*.



Quality and Content of the Learning Experience for Students

HOW IS ADVANCED BIOLOGY BEING TAUGHT?

Advanced Placement (AP) courses and to a somewhat lesser extent International Baccalaureate (IB) courses generally rely on the traditional transmission–reception mode of instruction, rather than a constructivist model in which students develop their own conceptual framework through inquiry-based, problem-centered active learning, as recommended by the *National Science Education Standards (NSES)*. Changes in teaching approach are needed in both programs, as discussed in Chapter 4.

Additional problems with AP courses, discussed in the following sections, are that they attempt to cover too many areas in a single year; they are often taught in one standard 47-minute period per day, which makes meaningful laboratory experience almost impossible; and they are driven by the need to prepare students for the AP examination rather than by concern for an optimal student learning experience. These conclusions are based on the panel’s conversations with AP teachers, the written guides for teachers of AP courses, and the emphasis on coverage in the AP tests.

WHAT BIOLOGY IS BEING TAUGHT?

The AP course outline is not up to date, and it overemphasizes environmental, population, and organismic (EPO) biology at the expense of molecular, cell, and developmental (MCD) and evolutionary biology. Although similarly out of date, the IB curriculum achieves a more appropriate balance of the EPO and MCD areas. The AP curriculum should include more on the process of science, including the responsible conduct of research, and the core IB curriculum should include more evolutionary biology. The core curricula of both programs should be updated to include concepts from current areas of rapid progress, such as genomics, cell signaling, mechanisms of development, and molecular evolution.

How Are the Curricula Developed?

It should be noted that the above criticisms and suggestions are also applicable to many introductory-level college biology courses. Since a major stated goal of the AP program is to allow students to place out of these courses, the AP curriculum is designed to include all the subject areas that might be encountered in *any* such introductory course (see the following section). To formulate the course outline, the College Board sends a curriculum survey questionnaire every 5 years to several hundred colleges and universities that have a history of granting AP credit. In the most recent survey (Educational Testing Service [ETS], personal communication, 1997), about 500 institutions were contacted, and only 56 responded. Of these 56, only about 6 are institutions that might generally be recognized as having first-rank biology programs (University of California at Berkeley, Carnegie-Mellon University, the University of Washington at Seattle, Cornell University, Dartmouth College, and Brandeis University), and 16–20 might be considered second-rank. Therefore, the AP curriculum has been based on a sample that is (1) very small and (2) not representative of the nation's best colleges and universities.

The recent report of the AP Commission (Commission on the Future of the Advanced Placement Program, 2001) recommends that the College Board change this approach to course development substantially as mentioned above, replacing the current survey-based curriculum with course outlines based on input from leaders in the biological disciplines, as well as pedagogy, “to ensure that current reforms and best practices are reflected in AP” (p. 12). This more proactive stance is intended to position AP as a lever for positive change in curriculum and instruction. The panel strongly endorses this change, which will undoubtedly help in addressing some of the concerns regarding AP that are discussed below.

The IB curriculum is formulated by an international consortium and also revised on a 5-year cycle. The consortium consists primarily of experienced IB teachers, most of whom are present or past examiners or moderators. (IB does not publish the committee rosters.) As noted earlier, because the IB curriculum is not constrained by the need to prepare students in specific areas for an advanced placement exam, it tends to be less comprehensive and more flexible than its AP counterpart, with 12 percent of class time allocated for options and 25 percent mandated for laboratory work over a 2-year period.

Keeping Up to Date

Biology is in an explosive phase of development. Almost every day there are articles in the newspaper about some new advance in biomedical

knowledge. Four of the most exciting areas of biological research today are the following:

- *Genomics*. Sequencing of the complete genomic DNA of humans and other organisms is making it possible to count the number of genes required for control of development and physiology and ultimately to determine the functions of all these genes.
- *Mechanisms of development*. This work is addressing how genes and their encoded proteins control the development of a fertilized egg into an adult organism.
- *Cell signaling*. Researchers are learning how cells talk to each other via signals from transmitting cells to receptors at the cell surfaces of receiving cells, as well as working out the pathways of interacting proteins that transduce a signal to the cytoskeleton and nucleus of the receiving cell to activate specific behaviors and changes in gene expression.
- *Evolution and the relatedness of organisms at the molecular level*. Researchers have come increasingly to realize that all organisms utilize not only similar molecules but also entire homologous systems of signaling and response for the same purposes in development and physiology.

Modern aspects of these topics are largely lacking from the AP and IB course syllabi.

Although it can be argued that secondary-level courses do not need to be up to the minute to be educationally valuable, courses that omit these topics lose an opportunity to engage students with issues in biology that are related to their daily lives.

Sample Suggestions

The following are some suggestions for addressing the shortcomings noted above:

- Expand discussion of the fluid mosaic model of membranes (dating from the 1970s) to include ligands, receptors, and signal transduction.
- Extend Mendelian genetics and the concept of mapping to the nucleotide sequence level.
- Use the rapidly advancing knowledge of developmental mechanisms as a review and synthesis of everything students have learned previously about gene expression, cell motility, signaling, and so on.
- Introduce the concepts of protein databases, sequence comparisons of homologous proteins, and building of sequence-based evolutionary trees.

In the IB course outline, almost all the material on evolution is in the optional curricular materials. Given that evolution provides the conceptual

framework for most of modern biology, it is essential that evolution be taught as a core subject and a basis for practical problem solving in all advanced high school biology courses.

As with any curricular reform, such changes are likely to pose challenges to the structuring of existing and time-honored courses. Difficult decisions will have to be made about how to accommodate these critical tenets of modern biology. By condensing and making greater attempts to integrate topics, however, many of these concepts can be introduced in ways that build upon other components of the courses and within the time allotted to teach them.

Balance

Table 3-1 compares the amount of time prescribed for three broad biological subject areas in the AP and IB curricula of 180 hours total (excluding the mandated 60 hours of laboratory in the IB course), and Table 3-2 shows time spent on more specific topics. Despite the explosive advances in MCD and evolutionary biology over the past 20 years, the overall distribution of time spent in the three major subject areas in Table 3-1 has not changed since the mid-1980s for the AP curriculum. In the AP course, 50 percent of class time is still spent on organismic biology and ecology and 32 percent on the structure of plants and animals (Table 3-2). This distribution does not reflect the current balance of emphasis in either biological research, the best instruction at the college level, or future career options for students. It is out of date and does not leave adequate time for teaching of cell and molecular biology.

TABLE 3-1 Distribution of Class Time in Major Biological Subject Areas in IB and AP Courses

% of IB ^a	Subject Area	% of AP ^b
22	Molecules and cells	25
31	Heredity and evolution	25
35	Structure of plants and animals, ecology	50
12	Optional topics	0

SOURCES:

^aBased on information from International Baccalaureate Organisation ([IBO] 1996), see Table 3-2. Figures in this column are percentages of nonlaboratory class time (75% = 181 hours); they do not include laboratory periods, which are mandated to be 25% of total time (59 hours; see Table 3-2). The evolution component (12%) of heredity and evolution is an optional topic.

^bFrom ETS (1999, pp. 3–5). Percentages of total class time, including laboratory.

TABLE 3-2 Percentages and Hours of Class Time Spent on Various Subareas of Biology in IB and AP Courses

Total Teaching Time		IB Curriculum Topics (1, etc.) That Correspond to AP Concepts		AP Teaching Concepts	% of AP Teaching Time Specified for a Concept (total hours 180)
% of IB Teaching Time Specified for a Concept (total hours 240)	Prescribed Teaching Hours				
5	12	2: chemistry of life (12 hr)		Chemistry	7
5	12	1: cells (8), 7: cells (4)		Cells	10
6	15	4.2: photosynthesis and respiration (5), 9: cell respiration and photosynthesis (10)		Energy	8
9	22	3: genetics (11), 10: genetics (11)		Heredity	8
5	12	2.7: genetic engineering, DNA fingerprinting, gene therapy (3) 8: nucleic acids and proteins (9)		Molecular Genetics	9
9	22	Option D: evolution ^d		Evolution	8
3	7	13: classification and diversity (7)		Diversity	8
4	10	16: plant science		Structure of Plants and Animals	32
16	38	5: human health and physiology (17), 11: human reproduction (5), 12: immune system (6), 14: nerves and muscles (6), 15: excretion (4)		Human Physiology	0 ^b
49		4: ecology (9)		Ecology Options ^c	10
9	22	E: neurobiology/ behavior; F: applied plant/animal science, G: ecology and conservation			0
Total: 75	181				100

continues

TABLE 3-2 Continued

Laboratory	% of IB Time in Labs (240 hours)	Prescribed Laboratory Hour	B Curriculum Topics (1-, etc.) That Correspond to AP Concepts	Laboratory Program	% of AP Time in Labs (180 hours)
4	10			Group 4 Interdisciplinary Inquiry Lab Project	0
7	16			Options laboratory work Laboratory Program	12 prescribed labs 0 ^d
14	33		6: investigations (15), 17: investigations (18)		
Total: 25	59				

SOURCES: Adapted from IBO (1996), ETS (1999).

^aFrom IB optional topics. Note that teaching evolution is an option in the IB program.

^bCovered under the concept Structure of Plants and Animals, which includes discussion of functions.

^cIB options can be used to create flexibility and modify emphasis in the curriculum. For example, basic human health and physiology is built into the core IB curriculum, but the optional topics include considerably more material on human physiology, physiology of exercise, and human nutrition. Good coverage of cell biology exists in the core curriculum, but additional material on cell biology and cell physiology is provided in the optional curricular materials. Basic nerve and muscle biology is covered in the core curriculum, but an additional unit of neurobiology and behavior is optionally available. The same two-tier system exists for ecology.

^dLaboratory time not specified (see the discussion later in this chapter).

BREADTH VERSUS DEPTH

A major problem with the AP course is that pressure to cover all of biology in less than a year precludes in-depth study and leads to superficial knowledge. In contrast, the IB program allows time for some in-depth study by subdividing the curriculum into core and options and by allowing 2 years for the Higher-Level (HL) course. The AP course needs to include more options, both in the curriculum and on the tests, to make its breadth manageable. One solution would be to have two AP courses—one emphasizing EPO and the other MCD biology—both with significant evolutionary emphasis.

Coverage of Topics in the AP and IB Courses

As noted above, because of the importance of scores on the comprehensive AP examination, AP instructors are under pressure to cover all of biology within a year, necessitating a fairly superficial treatment. Little time is available to explore any topics in depth. Although the ETS maintains that students do not need to know all topics well to be successful on the exam, many instructors, especially those who are less experienced, feel they must cover all the material.

In contrast, the IB curriculum builds in considerably more flexibility. First, there is a distinction between Subject Specific Core (SSC) and Additional Higher Level (AHL) material. Even together, these two categories do not cover all topics on the course outline and do not occupy the full instructional time, which also includes 12 percent set aside for optional topics to be chosen by the teacher. The range of optional curricular material (Table 3-2) allows IB instructors some level of control over the composition of their courses and the relative weights given to different areas of biology.

The IB program further alleviates the breadth versus depth problem by extending the IB Biology HL course over 2 years, thereby allowing more time for in-depth study of at least selected topics. Even for the 1-year AP course, less comprehensiveness should be acceptable if all entering students have had a previous survey course in introductory high school biology. The panel is pleased to note that a nonscientific survey of students taking the AP exams indicated that about 78 percent had had a full 2 years of biology, implying that they had taken a comprehensive biology course before taking the AP course.¹ As noted in Chapter 2, the panel believes this figure should

¹In an ETS questionnaire administered with the 1999 AP Biology exam, 61,952/79,212 students reported that they had taken biology for 2 years or more in grades 9–12, including their current courses. These data are limited in value as they are self-reported and were not verified, and students were not able to receive clarification of questions they did not understand.

be increased toward 100 percent. Finally, the IB course outline prescribes in some detail the degree of depth that should be achieved, whereas the AP course outline does not, although the same degree of depth knowledge may be demanded on the exams (see the examples in Appendix C).

As noted earlier, one approach to decreasing comprehensiveness and allowing more time for in-depth learning in the AP program would be to offer two separate courses—one emphasizing MCD and the other EPO biology (with evolution included in both). The panel finds the need for decreased breadth more compelling than the arguments against separation put forward previously by the College Board (AP Biology Teacher's Guide, 1995, p. 16). Some consequences of separation would be as follows:

- Increased costs to a school system if staffing, teacher training, and laboratory resources had to be provided for both courses. While this would probably not pose a significant problem for larger schools that already offer multiple sections of AP biology, it could be a significant burden for smaller school systems. However, the latter schools could choose to offer only one of the two courses.
- The need to develop separate AP tests for the two areas.
- Most significant, and representing the major stumbling block to any proposal for reform of the AP curriculum, scores on such restricted tests could no longer be considered as qualification to place out of a more comprehensive college introductory course. In fact, however, many of the better college biology programs have realized the impossibility of teaching a meaningful comprehensive introductory course and are instead offering alternative courses that are restricted along just these lines or further (see Chapter 5).

The “Less Is More” Paradox

The study of biology is of necessity broad; biology encompasses a huge variety of organisms and can be studied at many different levels of organization. In this regard, two pedagogical implications of the breadth versus depth issue are specific to biology. First, the study of evolution depends on the use of comparative methodologies and analysis across broad phylogenetic spectra. Synthesis and integration depend on inferring robust generalizations from diverse samples. This approach is applicable at many levels, from multiple sequence alignments in bioinformatics and molecular evolution to the use of morphological, behavioral, and ecological characters in phylogenetic classification. Second, biologists are deeply committed to preserving and appreciating biodiversity. If students are not able to understand the valuable contributions of diverse plants for food, clothing, fiber, housing

materials, and pharmaceutically active drugs, not to mention their aesthetic and historical importance for art, culture, and landscape, we will be missing a critical opportunity for environmental education.

On the other hand, recent research on learning indicates that often “less is more”; in other words, more real learning takes place if students spend more time going into greater depth on fewer topics, allowing them to experience problem solving, controversies, and the subtleties of scholarly investigation. More is not always better from other perspectives as well; for example, Shenk (1997) describes how we are being buried by information overload. Students need to learn critical data mining skills so they can find relevant information and distinguish meaningful from irrelevant data. Until they understand enough biology to focus on the key concepts in new material, they are likely to be swamped by details and unable to experience science as a process of creative thinking and problem solving.

The panel therefore recommends that more curricular flexibility be built into the IB and particularly the AP programs so that students can experience sustained, in-depth study of fewer areas. This study should be built around “big ideas” (as discussed below) and an understanding of the experimental method. It should be tightly integrated with similarly focused, in depth, inquiry-based laboratory experiences (also discussed below). Students need to be encouraged to think about the interrelatedness of the various disciplines of biology and the importance of interdisciplinary approaches to solving scientific problems. Emphasis should be placed on students’ ability to incorporate material they are learning into a meaningful conceptual framework.

Thus although some degree of breadth is necessary and desirable as argued above, *it should be defined by the degree of integration among different topics, not the number of topics covered*. If students understand the process of science and the hierarchy of interrelationships among topics they have studied in depth, learning new biological knowledge is easy because it fits into a conceptual framework that is already in place. Consequently, the selection of particular topics covered in a course is less important than activities designed to build understanding of science processes and a conceptual hierarchy, and courses need not strive for comprehensiveness of subject matter. Eliminating the use of AP and IB exam scores for automatic placement out of specific college courses, as recommended in Chapter 6, would allow advanced secondary-level courses, particularly AP, to evolve in this direction.

We argued in the preceding section that new and current subject matter should be introduced into the AP and IB biology curricula, while we have maintained in this section that these programs attempt to cover too many topics already. This is the paradox that makes curriculum design difficult, particularly for biology courses. We would resolve it by urging that currently

exciting subject matter relevant to students' everyday lives be included in the choice of recommended topics for consideration by teachers but that teachers be encouraged to apply the "less is more" principle and choose those areas for in-depth study that will create the most meaningful learning experience for students.

THEMES AND CONCEPTS

Both the AP and IB programs have stated themes around which the courses are theoretically organized. The eight themes of the AP curriculum mix philosophy and content, with some redundancy in the content themes, but appear adequate for their stated purpose. In the IB curriculum, there are only four stated themes, which surprisingly do not include two that appear to be essential—energy transfer and heredity. Themes in both courses are intended to provide integration of different topics, but the extent to which they are followed in presenting subject matter depends on the individual teacher. Particularly in AP courses, better integration of topics is needed.

Table 3-3 compares the stated themes of the AP biology course, the IB biology course, and the *NSES* Life Sciences content standards for grades 9–12. Equivalent or related themes are listed in the same row to the extent possible (heredity in the AP themes is subsumed under continuity and change). As seen from the disparities, these lists are somewhat arbitrary. The IB list

TABLE 3-3 Comparison of Stated Themes from AP and IB Biology Courses and the *NSES*

AP	IB	<i>NSES</i> ^a
Science as a process		Understanding scientific inquiry
Evolution	Evolution	Biological evolution
Energy transfer		Matter, energy, and organization in living systems
Relationship of structure to function	Structure and function	
Continuity and change		Molecular basis of heredity
Regulation	Equilibrium within systems ^b	The cell
Interdependence in nature	Universality vs. diversity	Interdependence of organisms
Behavior of organisms		
Science, technology, and society		Science and technology in local, national, and global challenges

SOURCE: Adapted from IBO (1996), ETS (1999), and National Research Council [NRC] (1996a).

^aThis list includes the six Life Sciences content standards, as well as one from Science as Inquiry and one from Science in Personal and Social Perspectives, all for grades 9–12 (NRC, 1996a).

^bEquilibrium is apparently used by the IB program (misleadingly) to mean steady state or homeostasis.

appears to have two glaring omissions, mentioned above. On the other hand, it could be argued that the AP list includes too many themes. There is some redundancy in the AP themes (e.g., between evolution and continuity and change), and some of their applications to the three major subject areas appear contrived.

More important than the specific themes listed is the way they are used. Recent research on learning (NRC, 1999) has documented the common-sense realization that experts in a given field have their knowledge organized into a hierarchical conceptual structure, with key concepts (“big ideas”) at the top, derivative ideas and topical knowledge below, and common themes connecting the concepts. An expert learning new knowledge can fit it into the appropriate place within the structure. To become expert learners, students must construct their own hierarchy, organizing topical knowledge under the appropriate concepts. Their instructors and instructional materials, therefore, need to emphasize the themes and big ideas and distinguish them from related topical knowledge.

The AP biology course description is introduced with a helpful definition of themes, concepts, and topics and how they are related in building a conceptual structure (ETS, 1999, pp. 2–3). It points out the importance of emphasizing key concepts over specific topical information and the way recurrent themes can be used to provide connections in the study of different topic areas. It claims “increasingly, the AP Biology Examination will emphasize the concepts and themes of biology and will place less weight on specific facts.” The panel hopes this is the case and that teachers will be encouraged to use themes to integrate diverse topics in the course. At present, however, there is little emphasis on such integration in the AP course outlines, recommended laboratories, and teacher preparation materials (see Chapter 4), so that integration depends on the initiative of the individual teacher. In particular, while the process of science is a stated AP theme, it appears clear from the outline that most AP laboratories are not inquiry based, so students have little chance to experience this process (see the next section).

Several of the same comments apply to the IB themes. The term “equilibrium” is used misleadingly to mean steady state or homeostasis. The rubric of themes and topics presented in the program description (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, pp. 7–14) again appears somewhat contrived in spots, and again the extent to which teachers use the themes in presenting subject matter is unclear. Nevertheless, with its more detailed course outline, the IB course appears to do a better job of integration, which is further enhanced by the Group 4 interdisciplinary project and the interdisciplinary thinking that pervades the IB program (as discussed later in this chapter).

The *NSES* content standards include topical areas as well as themes and therefore are not directly comparable, but there is nevertheless considerable overlap with AP and IB. One AP teacher who met with the panel gave her students the interesting assignment of comparing and trying to relate the AP themes and *NSES* standards as a way to understand them more clearly.

The above comments point to the need for more detailed guidance and development for AP biology teachers. This is a theme to which we return in subsequent sections.

LABORATORY WORK AND VARIETY OF LEARNING EXPERIENCES

Meaningful learning in biology must involve inquiry-based laboratory experiences that require students not simply to carry out a technique or learn a laboratory skill but also to pose questions, formulate hypotheses, design experiments to test those hypotheses, collaborate to make experiments work, analyze data, draw conclusions, and present their analyses and conclusions to their peers (NRC, 1996a).

One of the major differences between the AP and IB programs is the extent to which they meet these ideals. The AP laboratory exercises tend to be “cookbook” rather than inquiry based. They are not emphasized or tested adequately on the exam and hence may be neglected. Written assignments that could integrate laboratories with the curriculum are not required. Schools are not evaluated by the College Board for adequate laboratory facilities. Although the IB laboratories are also largely not inquiry based, 25 percent of time in laboratories is mandated, portfolios describing students’ laboratory work are an integral part of the basis for evaluation, an extended writing assignment is required, and schools applying for IB status are initially reviewed and certified as having adequate laboratory resources and facilities. Yet both programs need more inquiry-based laboratory work. Learning experiences should be aligned with those set forth in the *NSES*. Although including laboratory performance in the AP exam is probably impractical, a portfolio of laboratory work should be made part of a student’s record, and universities should be encouraged to evaluate portfolios in advanced placement decisions. AP should certify that school facilities and resources can support college-level laboratory instruction before allowing courses to be designated as AP. The initial evaluation and continued surveillance of student work carried out by the IB program (see below) provide an appropriate model for implementing this recommendation.

The AP manual suggests “since one-fourth to one-third of the credit in comparable college courses is derived from laboratory work, AP courses

should likewise emphasize laboratory work.” However, there are several problems with the 12 recommended AP laboratories:

- They are highly prescribed, not inquiry based. The required laboratory write-ups involve filling in data tables or blanks, along with some “short” more extended responses. A sample AP laboratory is described in Appendix D. It is extremely directed; a student could work through it without gaining any understanding of what has occurred at the molecular level and its significance.
- Although the AP biology course outline specifies that all 12 laboratories should be carried out, there is no check on whether the laboratories are completed. Questions dealing with laboratory material comprise only a small proportion of the exam. Moreover, many questions assess content knowledge related to the laboratory rather than protocol and process skills, so that the information can be obtained from reading or lecture without conducting the laboratory. (A few questions are better; for example, there should be more questions like those dealing with the photosynthesis laboratory.) Videos of the laboratories being carried out by others are available to familiarize students with protocols. Therefore, it is impossible to tell from AP test results whether students have actually performed laboratory exercises. The panel heard anecdotal evidence that teachers wishing to maximize preparation time for the exam minimize the laboratories and may skip some altogether. Therefore, meaningful laboratory experiences are not guaranteed by the AP program but rather depend on the skill and initiative of individual teachers.
- The 12 laboratories for which information is provided to teachers are an unnecessarily restricted set. Teachers who would like to use alternative laboratories may have neither a ready source for the necessary equipment and protocols nor the experience to use them. The limited teacher development available (see Chapter 4) is restricted to the 12 recommended laboratories.
- The AP program has no mechanism for certifying that teachers are competent to teach the laboratories or, just as important, that a school has the resources to support them with the required equipment and supplies. Consequently, students in poorer schools may be limited to learning about laboratories through videotapes and the textbook.

In contrast, the IB laboratories are much less prescribed and require that students play a more active, investigative role (see Appendix D). Laboratory portfolios are used for formative assessment throughout the course in documenting student understanding of laboratory practices and student accomplishment. There are many laboratories from which to choose, and the teacher is given considerable latitude in their selection. Schools and teachers must be initially certified before they are allowed to offer an IB biology course,

and their ongoing performance is assessed through sample laboratory reports that must be submitted periodically to IB international headquarters. The IB laboratories offered may differ from school to school, depending on teacher preparation and availability of resources. However, the initial evaluation process demands that each school plan an acceptable series of laboratories commensurate with its resources before certification is granted.

To address the above problems, the panel makes the following recommendations:

- Both programs should move toward including more inquiry-based laboratory work in accordance with the *NSES*. Laboratory work should involve students in the active learning of science by doing science. The AP laboratories in particular should include more activities that engage students in analysis of complex data, modeling, data mining, generation of hypotheses and experimental designs, and statistical analysis. There should be built-in opportunities for reflection and peer review of work, as well as collaborations among students, faculty, and experts from the community.
- The College Board should assess courses and schools directly rather than only through the performance of their students on the AP exam. The AP program should include a certification mechanism to ensure that teachers of AP biology are qualified and that schools have the resources to support planned laboratory investigations. Because meaningful laboratory teaching is almost impossible in a single class period, schools wishing to offer AP biology should be strongly urged to schedule at least one uninterrupted 2-hour period per week for laboratory work.
- The AP exam should include more questions that assess student understanding of laboratory protocols and processes, understanding that can be gained only by actually carrying out experiments. In addition, the AP exam should include assessment of a portfolio of laboratory work by the ETS in addition to the summative exam.
- Extensions to the 12 recommended AP laboratories should be provided so that students and teachers can go beyond the basic exercises if they have the time and resources to do so.
- The AP program should provide or accept many more alternative well-tested laboratories, which could be distributed via CDs and the Internet, to give teachers a choice in the laboratories they present. Teachers should be encouraged not to limit themselves to the 12 currently provided AP laboratories. The Web is already an important source of laboratory exercises through sites such as those of Access Excellence (Genentech Corp.), CIBT (Cornell Institute for Biology Teachers), ABLE (Association of Biology Laboratory Educators), and ACUBE (Association of College and University Biology Educators). Access information for these Web sites is provided in Appendix E. Alternative laboratories could be grouped into categories and teach-

ers asked to conduct a certain minimum number of laboratories from each category. In addition to AP and IB teachers and students, college and university scientists should be involved in the development of additional appropriate laboratories, including laboratory and field exercises. Both ethics and environmental responsibility should be addressed in laboratory work. It would be useful to consider the development of laboratory blocks in which a group of progressive laboratory exercises is built around a model organism suitable for molecular genetic analysis, such as yeast, the alga *Chlamydomonas*, the nematode *C. elegans*, or the fruit fly *Drosophila*. These organisms have many advantages for use in advanced high school biology laboratories, including (1) they are inexpensive to grow and maintain, (2) they are convenient for genetic experiments, and (3) there are national genetic stock centers from which a variety of mutants is available without charge.

- The AP program should provide or certify more teacher development and ongoing support in relation to laboratory teaching for both the 12 AP laboratories and alternatives. The IBO, which already provides considerable support for IB laboratories through its 3-day teacher training workshops, should consider expanding that support. The best mechanism for doing so may be university-based weeklong workshops. All prospective AP teachers should be required to attend at least one weeklong workshop before being allowed to commence teaching AP biology. The CIBT program at Cornell University is a model. Such programs often are able to provide loan equipment, supplies, and reagents in addition to teacher training. The AP and IB programs should evaluate and certify such college- and university-based workshops for their teachers.

INTERDISCIPLINARY EMPHASIS

There is little evidence of interdisciplinary emphasis in the AP course outline. In contrast, the entire IB program, including its biology course, rests on the importance of interdisciplinary connections in learning. The IB program is exemplary and far superior in this regard. The AP program should consider changes that would promote interdisciplinary learning.

Interdisciplinary activities in the IB program include an extended essay and a course required of all students on the Theory of Knowledge, which ties together all six groups of courses in the curriculum (IBO, 1996). Another particularly desirable interdisciplinary requirement is the Group 4 laboratory project, in which students from several different advanced courses (e.g., biology, chemistry, physics) work together as a group to solve an experimental problem, often a local one involving the environment or the community (see the brief description in Appendix D). While restructuring the AP

program in the near future along more interdisciplinary lines may not be practical, small steps could easily be taken in this direction, such as:

- Combining advanced biology and chemistry into a 2-year course team-taught by a biology teacher and a chemistry teacher.
- Involving students from two or more AP science courses in joint interdisciplinary, community-oriented, problem-solving laboratories.

ASSESSMENT

With regard to mastery of content knowledge, concepts, and applications (see the charge to the panel in Appendix A), both the AP and IB exams test primarily rote learning.² In the IB assessment process, evaluation of a portfolio, laboratory notebooks, and other work provides more perspective. The AP exam should include more free-response questions and evaluation of laboratory work, and both should test more concept knowledge. With regard to application of knowledge to other courses and situations, the AP exam is limited by a lack of interdisciplinary emphasis, while the IB assessments include such applications. As recommended above, the AP course and exam would benefit from more interdisciplinary emphasis.

Excessive use of multiple-choice and fill-in-the-blank questions assessing factual details on both AP and IB examinations encourages the rote learning of many facts at the expense of understanding larger concepts. It is encouraging to note that the AP biology exam was redesigned in the mid-1990s to include more free-response or essay questions and fewer short-answer questions and that there are plans to increasingly emphasize concepts and themes and deemphasize retention of specific facts (Commission on the Future of the Advanced Placement Program, 2001, p. 3). Both exams should move in this direction. Additional improvements could include the following:

- More questions that assess laboratory skills, e.g., scenario questions requiring analysis of datasets, quantitative analysis, and testing of multiple working hypotheses.
- For AP exams, document-based questions (already used in IB exams) requiring students to read a brief biology article and write about it.

²Based on reports of teachers interviewed and the panel's inspection of recent AP and IB exams.

- Open-ended questions with no prescribed answers, asking students to discuss a currently exciting topic they have studied. Questions of this type would promote study of such topics in the AP course.

However, the panel's primary recommendation is that assessment in the AP program should be extended to include formative evaluations of laboratory notebooks, presentations to peers, and other activities during the course in addition to the final high-stakes summative examination.

Finally, as pointed out above, there is a great need in the AP program for assessment not only of students but also of teachers and schools that offer AP biology courses to ensure minimum standards of quality.

4

Teachers and Teaching

IS CURRENT KNOWLEDGE OF LEARNING AND PEDAGOGY BEING APPLIED?

The Advanced Placement (AP) and to a lesser extent the International Baccalaureate (IB) biology courses are taught inconsistently with current knowledge in several ways, some touched on earlier and more discussed below. Inconsistencies include rapid-fire course coverage at the expense of depth of understanding; continued reliance on the traditional learner-passive, transmission–reception model of learning; failure to specifically target common known misconceptions; limited use of history as a route to understanding in the context of people and society; failure to keep pace with new technological and instrumentation opportunities, such as learning through computer modeling of biological systems and hand-held data collection and analysis equipment for field work; overreliance on multiple-choice and fill-in-the-blank test questions; limited experiential and inquiry-based learning in the laboratory, including the “persuasion of peers” phase crucial to the scientific process; and in general, lack of an overall research-based learning theory that can drive the design of instruction and assessment.

Classroom practice should be driven by research on learning and teaching. Following are key findings from *How People Learn: Bridging Research and Practice* (HPL2; National Research Council [NRC], 2000a, pp. 10–15):

- Teachers need to probe students’ prior knowledge and engage it in their teaching.
- To develop confidence in an area of inquiry, students need to build a sound conceptual framework and structure it in ways that facilitate retrieval and application.
- Students need to learn how to monitor their own understanding (metacognition) and take an active role in their own learning.

These findings have concomitant implications for teaching (NRC, 2000a, pp. 15–19):

- Teachers must be aware of students' prior and evolving knowledge. Therefore, more emphasis should be placed on formative assessment.
- Fewer topics must be taught but in greater depth and with more examples, in order to yield a sound conceptual foundation.
- Teaching of metacognitive skills should be integrated with discipline-based instruction.

HPL2 stresses that “a benefit of focusing on how people learn is that it helps bring order to a seeming cacophony of choices” (p. 18). It continues with a variety of recommendations that are updated in *Inquiry and the National Science Education Standards* (INSES; NRC, 2000b). For example, *INSES* suggests that inquiry is simultaneously a way of teaching and learning, a way of answering questions, and intrinsic to scientific investigation. Thus, learners should (pp. 13, 25):

- Be engaged by scientifically appropriate questions.
- Use evidence to build explanations.
- Weigh alternative scientific explanations.
- Communicate and justify their explanations.

The AP and IB programs need to move toward reflecting this transformation from curricula that are directed by the teacher (as transmitter and corrector), the text, exams, and material to curricula that are learner directed. Doing so will involve attention to (1) student knowledge construction based on investigation, analysis, and problem solving; (2) peer review and collaboration to continuously monitor student knowledge; and (3) efforts to address real problems of the local community and ecosystem. On average during a calendar year, students spend less than one-seventh of their time in school. During waking hours, they spend four times as much time in their homes and communities than in school (including more time watching television than in school; see NRC, 2000a, p. 23). Thus, “a focus only on the hours that students currently spend in school overlooks the many opportunities for guided learning in other settings.”

TEACHER PREPARATION AND PROGRAM QUALITY

Many teachers at the secondary level are unprepared with regard to content knowledge to teach college-level biology, and many schools that offer AP programs do not have the resources to support adequate labora-

tory instruction. The College Board should evaluate and certify AP schools and teachers in some manner similar to that in which the International Baccalaureate Organisation (IBO) initially evaluates and certifies its schools and teachers.

Some of these issues have been addressed in Chapters 2 and 3. Through its application and interview process, the IBO ensures that new IB schools are qualified and that schools have the necessary resources for the program's required laboratory activities. Once an IB school has been certified, the IBO monitors teachers through its internal assessment program. For AP schools, however, these issues represent basic concerns, including the following:

- Teachers who have not been certified to teach an AP course except by a local school system and may not even have a B.A.-level education in biology are teaching courses that can receive college credit. (Data are not currently available on what proportion of AP biology teachers do not hold a B.A. degree in biology. The panel strongly urges the College Board to obtain these data and make them available.)
- An inexperienced teacher can be assigned to an AP course at the last minute, with no laboratory experience and no preparation beyond the "Acorn Book" (Educational Testing Service, 1999) and a set of previous exam questions.

These concerns should be addressed by:

- Mandatory evaluation. While some teachers with a B.A. degree in biology and some experience are undoubtedly capable of teaching college freshman-level biology, others may not be. An M.A. degree in biology, involving some experience with research, would clearly be preferable for teaching the kinds of inquiry-based laboratories that would conform to the *NSES* and *INSES*. However, rather than mandating a certain level of preparation, the panel reiterates its recommendation that the AP program institute an assessment process, including teacher interviews, that teachers and schools would have to undergo before offering an AP biology course for the first time.
- Mandatory teacher preparation. The panel reiterates that no teacher should be assigned or certified as above to teach an AP biology course without having had the opportunity to participate in at least a 1-week summer workshop focused primarily on laboratory activities.

TEACHER DEVELOPMENT AND SUPPORT

More inservice teacher preparation and support are needed, and more attention should be paid to pedagogy in manuals and workshops, particu-

larly for AP teachers. Neither the IB nor AP program requires or offers much in the way of continuous professional development of teachers as a prerequisite for participating and remaining in the program.³ According to anecdotal evidence gathered by the panel, most teachers have little opportunity to collaborate with one another in developing adaptations and implementations of more progressive curricular approaches. The AP workshops currently offered by the College Board are 1-day or half-day meetings that focus primarily on recent developments in the AP examination and how to prepare students for the exam. Both programs need

- More instruction in and discussion of inquiry-based learning and pedagogy in general in the materials prepared for teachers, following the guidelines of the *NSES* and *INSES* (see the preceding section).
- More frequent workshops that include discussion of recent developments in biology and pedagogy.
- More training and ideas for laboratory activities, including the recommended or alternative laboratories, disseminated through workshops, CDs, or Internet sources (see Chapter 3).
- More involvement of the programs in establishing peer support groups for teachers in the same locale and perhaps via the Internet for geographically isolated teachers. (IB already does this to some extent via the IBO Online Curriculum Center.)

INFLUENCE OF CURRICULA AND ASSESSMENTS ON TEACHING APPROACHES

As noted earlier, the perceived need for comprehensiveness and the single high-stakes exam of the AP program in particular encourage teachers to promote rote learning in order to cover all the necessary material. Both curricula, but that of AP in particular, are burdened by the perceived need to cover many areas of biology and enable students to achieve high scores on an exam that assesses their breadth of knowledge. Consequently, both curricula emphasize memorization of facts and promote strategizing for the exam and even repeated rehearsals of test taking, often at the expense of gaining a meaningful understanding and appreciation of biology. The panel learned anecdotally that students' specific results on both the AP and IB examinations are not made available to teachers for feedback on the effectiveness of their teaching. However, IB teachers do have access to analyses of student responses by section and question for each participating examination group. Such information can be valuable to teachers by allowing

³Based on teacher interviews and review of AP and IB materials by the panel.

them to assess the effectiveness of their teaching within specific areas of the curriculum. To move in a more constructive direction, we reiterate our recommendations that:

- The exams should include more data analysis and problem-solving questions that emphasize understanding of concepts rather than factual knowledge of specific topics. More free-response questions would also be desirable, although we realize that such questions add substantially to the cost of administering the exams. It appears inevitable that to some extent the exams will always drive instruction in the courses; if the exams can be changed, it will be easier for the courses to evolve in constructive directions. Individual students' exam answers should be made available to their teachers.
- Assessments other than the final summative exam—for example, review of laboratory portfolios—should be carried out in evaluating the performance of AP students.
- Performance on AP and IB exams should no longer be used by colleges to allow automatic placement out of specific introductory courses, so that curricula of college introductory courses will no longer drive the content of the AP and IB courses and exams. The rationale for this recommendation is developed further in Chapter 6.

CHANGING EMPHASES IN ASSESSMENT: ARE THE NSES RECOMMENDATIONS BEING FOLLOWED?

The recommendations in the NSES with regard to assessment are not being followed to a sufficient extent. For example, both AP and IB exams emphasize assessment of what is easily measured: rote learning of facts and concepts rather than what is most highly valued—hierarchically structured conceptual knowledge and understanding of scientific processes.

Table 4-1 summarizes the NSES recommendations for changing the standards for assessment (NRC, 1996a). It is clear from the previous discussion that many of these standards are not being followed most of the time. The panel's recommendations above and in Chapter 6 are intended to help move the AP and IB assessments in these directions.

ALTERNATIVE COURSES AND PROGRAMS

As noted earlier, the panel had neither sufficient time nor adequate resources to allow in-depth analysis of alternative programs in advanced biology beyond those of AP and IB. Among the exemplary programs that may be leading the way in advanced secondary-level science education are those at the Austin Academy of Mathematics and Science, the Bronx High

TABLE 4-1 *NSES* Recommendations for Changing Standards for Assessment

Less emphasis on:	More emphasis on:
Assessing what is easily measured	Assessing what is most highly valued
Assessing discrete knowledge	Assessing rich, well-structured knowledge
Assessing scientific knowledge	Assessing scientific understanding and reasoning
Assessing to learn what students <i>do not</i> know	Assessing to learn what students <i>do</i> understand
Assessing only achievement	Assessing achievement and opportunity to learn
End-of-term assessments by teachers	Students' ongoing assessments of their own work and that of others
Development of external assessments by measurement experts alone	Teachers involved in the development of external assessments

SOURCE: NRC (1996a).

School of Science, the Illinois Mathematics and Science Academy, the North Carolina School of Science and Mathematics, and the Virginia Governor's Schools. Forward-looking characteristics of these schools include flexibility and fluidity in the classroom environment. There is also less focus on the teacher as the source of information and more on students working independently or in collaborative groups, guided by extensive use of contracts for specified projects. Projects often involve generating new knowledge and solving real problems related to the local or regional environment. In general, there is more emphasis on teaching the tools and methods of learning and less on specific content.

COORDINATION BETWEEN HIGH SCHOOLS AND COLLEGES

University-sponsored outreach programs can be a major resource for high school advanced biology programs and should be encouraged. More communication between high schools and universities—in both directions—would be helpful in fulfilling the needs of both institutions and in developing curricula and assessments.

An increasing number of universities are sponsoring outreach programs for local and regional K–12 educators. Several such programs are supported by the Howard Hughes Medical Institute and the National Science Foundation. These programs can provide important regional foci for teacher development in connection with advanced high school courses in biology. They typically offer workshops for teachers; provide laboratory materials for use in the schools; and involve faculty, graduate students, and sometimes undergraduates who work in the classrooms with a regular teacher to provide enrichment science instruction.

One example, described earlier, is the Cornell Institute for Biology Teachers. Another is the outreach program of the Department of Molecular Biotechnology at the University of Washington, Seattle. Students participating in this program sequenced small segments of the human genome and submitted them to the central databases of the Human Genome Project. Another excellent outreach program in the Seattle area is sponsored by the Fred Hutchinson Cancer Center. The Washington University School of Medicine in St. Louis provides a summer teachers' workshop on DNA laboratories, followed by a continuing program of support. When ready to use one of the laboratories, a participating teacher contacts the outreach office and is loaned a kit that includes all the reagents and equipment needed. Graduate students from the Hughes-supported "Science Squad" from the department of MCD Biology at University of Colorado, Boulder, assist teachers in the Denver area with specialized laboratories and classes using resources supplied by the program. A "teaching to learn, learning to teach" program at University of California, Davis gives undergraduate biology majors academic credit for assisting local teachers and has inspired many participants to adopt K–12 teaching as a career goal. The BioQUEST Curriculum Consortium at Beloit College provides teacher workshops and curricular materials emphasizing the use of computers in laboratory simulations, quantitative data analysis, problem posing, and problem solving.

In general, these programs provide an important link between university and high school biology instructors. The panel believes further liaison activities and exchanges of information in both directions, as already practiced in some programs, would benefit both constituencies, particularly in university communities.

There are a number of other ways in which universities can support advanced biology teachers or their schools. Examples are as follows:

- In schools where qualified teachers or resources are not available, teaching of AP courses by local university faculty using university facilities.
- Furnishing of ideas and materials for laboratory exercises by university faculty to local teachers (or not so local, via the Internet).
- Guest discussions or lectures by university faculty, known to be effective with high school students, who can serve as role models with research experience.
- Research opportunities for advanced students and teachers who want to get a taste of laboratory investigation.
- Surplus laboratory equipment and supplies.
- Research results (e.g., in the form of video-recorded observations or datasets) for discussion and analysis in AP classes.
- Online access to university library materials.

Additional ways in which university faculty can benefit science teaching in high schools are discussed in the NRC report entitled *The Role of Scientists in the Professional Development of Science Teachers* (NRC, 1996b).

At the same time, advanced biology teachers and their schools have much to offer universities. Examples include the following:

- Teaching experience for research associates, graduate students, and undergraduates who may be considering teaching as a career or just enjoy it (or both).
- Talented students and teachers interested in research apprenticeships during the summer or the academic year.
- Discussion of effective teaching practices. The Hughes program has released a video showing how university faculty can learn from master teachers at the secondary level.

There are also a number of useful joint activities for university faculty and teachers of advanced biology:

- Discussions and cooperative development of curricula. Most university faculty who teach introductory courses in biology are unfamiliar with the advanced biology taught in high schools.
- Discussions and cooperative development of laboratory experiences. A university researcher may have an experimental organism or problem that a creative high school teacher can see how to exploit as a learning tool.
- Discussion and cooperative development of outreach activities and grant applications for their support.
- Joint teaching of an AP course by a secondary teacher and a university faculty member.
- Regular joint social activities, perhaps in the form of a “biology learning club,” at which university and high school biology faculty could get to know one another and discuss common interests and concerns. In most university communities, there is little contact between the two groups.

Finally, as emphasized elsewhere in this report, there is a need for *systemic* reform of biology teaching, not just at the secondary level but throughout the education system, to conform to recent knowledge about how people learn and to the *NSES*. Many college introductory courses suffer from the same shortcomings as those identified in this report for high school advanced study courses, such as too much emphasis on comprehensive coverage and rote memorization of facts and too little active, inquiry-based, or problem-based learning. Colleges and universities should revise or improve introductory biology courses as necessary to bring them into line with the

recommendations made in this report for high school advanced study courses. Rectifying the current situation is important for two reasons. First, college-level introductory courses contribute to problems with AP courses in particular because the content of those courses has been driving the AP biology curriculum. Second, inadequacies of many primary as well as secondary school courses may stem directly from the mode of instruction experienced by teachers as college students.

5

Outcomes

USE OF AP AND IB COURSES FOR ADVANCED PLACEMENT

There are many concerns with the use of Advanced Placement (AP) and International Baccalaureate (IB) scores for granting of advanced placement. Some top-ranked colleges do not accept either AP or IB credit or both. For a variety of reasons discussed above, some AP and IB biology courses are not of high enough quality to be appropriate for college credit. And the AP biology course as presently constituted is too environmental, population, and organismic (EPO) oriented to be an appropriate substitute for a first-year college molecular, cell, and developmental (MCD)-oriented biology course.

Colleges and universities use performance in AP and IB biology, primarily as measured by test scores, in a wide variety of ways (see the discussion of results from the parent committee's survey of deans of admission in Chapter 2 of the committee's full report). In some states, state law mandates certain amounts of college credit for students who pass the AP test with specified scores. At the other extreme, some universities offer neither credit nor advanced placement for achievement in AP or IB programs, believing that their own introductory courses are essential for later success in the biology major (see the discussion in the next section). Between these extremes, some offer credit toward graduation but no advanced placement, while others offer advanced placement but no credit toward graduation. These discrepancies in the ways AP and IB scores are used is one of the panel's reasons for believing that the use of the programs for automatic advanced placement could be eliminated without affecting the programs' other existing and potential benefits (see Chapter 6).

PREPARATION FOR ADVANCED COLLEGE COURSEWORK

Because of the lack of in-depth study in many AP courses, students who place out of first-year college courses may be at a disadvantage later at institutions where the introductory course is effectively taught. The available data on how well the AP courses prepare students for advanced work in the field may be misleading.

The panel concluded that allowing students to place out of introductory biology courses automatically on the basis of AP and IB test scores is a poor idea. The rationale for advanced placement rests on three assumptions: (1) that most AP and IB biology courses are highly similar, (2) that most college and university introductory courses are highly similar, and (3) that most AP and IB courses are equivalent to college-level introductory courses. All three assumptions are invalid.

Regarding the uniformity of AP and IB courses, evidence discussed above and self-reported data from AP examinees suggest that significant numbers of AP students do not perform laboratory exercises.⁴ Different school systems differ widely in their abilities to provide teacher preparation and in-service training for AP teachers, in the quality of their laboratory facilities, in their equipment and supply budgets, and in their scheduling and allocation of time for AP courses. Neither teacher qualifications nor school resources and facilities are certified by the AP program; the result is an extreme lack of uniformity in the quality of AP courses. IB courses are more likely to be uniform in quality, for reasons discussed previously.

Regarding the uniformity of college-level introductory courses, there is a growing trend at colleges and universities to create integrated biology programs for majors in which no course is designated as “the introductory course.” At the many universities that still offer broader designated beginning courses, there are now often two different tracks or majors in biology—one MCD oriented and one EPO oriented—with appropriately different introductory courses. At many universities, therefore, allowing biology majors to bypass a required course on the basis of AP and IB examinations, which test for broad superficial knowledge of all areas of biology, is inappropriate. With regard to nonmajors, those at some universities can be exempted from a biology distribution requirement on the basis of a high AP or IB test score.

⁴In an Educational Testing Service (ETS) questionnaire administered with the 1999 AP Biology exam, 8,708/78,745 students reported spending no time doing laboratory work for AP Biology class. These data are limited in value, however, as they were self-reported and were not verified, nor were students able to receive clarification of questions they did not understand.

The panel believes it is similarly unwise to allow students to fulfill entire distribution areas in a college education using AP or IB placement credits (see Chapter 6).

Regarding the equivalence of high school and college instruction, there is no doubt that the best AP and IB courses are superior to many introductory college courses. Given the variation mentioned above among AP courses in particular, however, it appears clear that an assumption of equivalence between all AP and IB courses and college-level introductory courses cannot be valid. Evidence sometimes cited to support equivalence was presented in an ETS research study by Morgan and Ramist (1998). The results of this study indicated that, at a limited sample of colleges and universities, AP students with test scores of 3, 4, or 5 who bypassed their introductory college biology course performed as well (or better) in advanced college biology courses as students who had taken the introductory course. While the panel does not doubt these findings, we note that this study did not control for student quality. An alternative interpretation of the findings could be that AP courses attract the brightest and most highly motivated students, who do better in advanced courses simply because they are superior learners. This effect would be amplified at institutions where the majority of superior incoming students are granted advanced placement, thereby depleting the introductory courses of such students. Therefore, the panel believes this study neither validates nor invalidates the claim that AP courses are equivalent to first-year college introductory courses. To our knowledge, no comparable studies have been carried out on students granted advanced placement based on an IB course in high school. Clearly, more and better research is needed on this important point. The panel therefore makes the following recommendations:

- Biology majors should not, in general, be allowed to use AP or IB biology test scores as the sole basis for automatic placement out of an introductory college-level course or any other specific required course.
- Nonmajors should not be allowed to bypass a subject-area distribution requirement on the basis of AP or IB test scores alone.
- AP and IB test scores should be used only to grant elective credit toward a college degree.

The rationale for these recommendations is further elaborated in Chapter 6.

TURNING STUDENTS ON TO BIOLOGY

Greater emphasis on inquiry-based learning in AP and IB courses would motivate more students to pursue further training in biology and biology-

related careers in research, teaching, or biotechnology. Although a skilled teacher can teach within the AP framework and still involve students in a way that excites them, the emphasis on passing the exam and the resulting shallowness of the curriculum encourage rote learning that is unlikely to turn students on to biology. The IB program, with more emphasis on in-depth study and inquiry-based laboratory work, appears to do a better job in this regard. Motivation in the AP course is primarily extrinsic, resulting from the desire to excel and the pressure of the high-stakes examination, while motivation in the IB course appears more likely to be intrinsic, resulting from intellectual involvement with the material. Many of the recommendations made above—for better teacher preparation, more emphasis on inquiry-based laboratories and big ideas, and less comprehensiveness and rote learning of specific facts—would promote more intrinsic motivation and consequently more excitement about the study of biology in the AP course.

6

Summary and Discussion of Recommendations

PRIMARY RECOMMENDATIONS

This section presents the three recommendations the panel considers most important, along with a summary discussion of each.

Recommendation 1

1. The College Board should certify schools and teachers that wish to present Advanced Placement (AP) biology courses and should provide suitable training opportunities for prospective AP biology teachers. The College Board should also develop procedures, such as those used by the International Baccalaureate Organisation (IBO) in the IB program, for ongoing assessment of AP programs and teachers through regular sampling of student work; such sampling should also be used for assessment of student achievement in addition to the final examinations.

The panel realizes that implementation of such a system is a daunting undertaking. Whereas the IBO presently oversees about 350 programs in the United States, the College Board must deal with about 7,000 programs, and this number is growing. Nevertheless, we believe strongly that a more organized system of preservice training and certification will be necessary to achieve greater uniformity in the quality of AP biology instruction.

2. Certification and assessments of both the AP and IB programs by the College Board and the IBO, respectively, should be designed to ensure that changing emphases in standards for teaching, professional development, assessment, and content, as set forth in the *National Science Education Standards (NSES)*, are being implemented. Teacher preparation and inservice workshops in both programs should place

more emphasis on pedagogy—how to facilitate student-centered, problem-oriented, inquiry-based learning—and on recent results of research on cognition and learning.

Justification for this recommendation is presented throughout the report. It should be noted that implementation of this recommendation is not dependent on greatly increased resources for less wealthy schools. Inquiry-based learning does not require access to expensive equipment or elaborate methods. Inquiry-based laboratories can be conducted on a low budget, as many excellent AP teachers have demonstrated.

3. Colleges and universities should be strongly discouraged from using performance on either the AP or IB examination as the sole basis for automatic placement out of required introductory college courses for biology majors and distribution requirements for nonmajors.

Several arguments for this recommendation have been presented earlier in this report. This recommendation may at first appear to run counter to the major purpose of the AP program as well as to its name. On the contrary, however, as discussed below, its implementation would have many desirable consequences and few disadvantages for both programs.

Distinguishing Automatic Advanced Placement from College Credit

The term “advanced placement” is often taken to mean the following: for majors in biological sciences, exempting students from specific courses normally required for the major, and for nonmajors, exempting students from general distribution requirements in the life sciences. The term can also denote the granting of either elective credit or general unit credit, which advances the student toward graduation on the basis of college-level work done in high school.

The panel is recommending only discontinuation of *automatic* advanced placement in the first sense, that is, the practice of exempting students from a required course on the basis of AP or IB exam scores alone. We do not discourage granting such advanced placement on a case-by-case basis (i.e., nonautomatically) if the decision to do so is made responsibly by the relevant college department. This means that a college or university department should determine according to its own criteria that there is a good fit between the student’s high school course and the required course in question in terms of both level and subject matter and that granting credit is in

the best interests of the individual student. Such criteria are already used for granting transfer credit between colleges; they should be applied to advanced placement decisions as well.

Many college departments already use such criteria to grant or refuse advanced placement to incoming first-year students. The panel reiterates that its recommendation applies only to those that offer advanced placement automatically. A few states have passed legislation that mandates automatic advanced placement based on exam scores alone in all public colleges. Such legislation works against the best interests of students and should be strenuously opposed.

Benefits of Implementing This Recommendation

Several undesirable aspects of the AP and IB programs discussed in this report tend to be maintained by a complex set of historical precedents; vested interests; and interdependencies among schools, school boards, state governments, teachers, parents, students, universities, the Educational Testing Service (ETS) and the College Board, and the IBO. Implementing this recommendation would cut this Gordian knot, freeing both programs to evolve in desirable directions and greatly facilitating the implementation of other changes recommended by the panel. It would sever the current link between the AP (and to a lesser extent the IB) examination and the content of first-year college courses in biology (as perceived by the respondents to the flawed AP survey; see Chapter 3), which provides an inappropriate standard by which to base the biology taught in high schools. This in turn would free the AP exam in particular, but also the IB exam, to evolve into better instruments for assessing the understanding of important concepts and the process of science, reasoning power, and analytical ability, with less emphasis on knowledge of specific biology facts. Such decoupling could also allow decreased emphasis on the exam itself, with incorporation of more formative assessments performed during the course into the judgment of student performance. These changes would have the effect of freeing the AP curriculum in particular, but also the IB curriculum, from the current preoccupation with comprehensiveness, allowing more in-depth, inquiry-based exploration of selected topics depending on the interests and skills of individual teachers and the local and regional environments of particular schools.

Disadvantages of Maintaining the Status Quo

Several arguments can be made against the current practice of granting automatic advanced college placement on the basis of AP and to a lesser

extent IB examination scores alone. These arguments, reiterated from above, include the following:

- The lack of depth in many AP courses leads to superficial knowledge rather than real understanding of biology, which may handicap students in subsequent biology courses.
- Colleges and universities differ widely in the nature and emphases of their introductory courses. The assumption that the AP program can provide universal preparation for any college-level introductory course is unrealistic.
- Since the AP program does not certify teachers or schools, an AP course may be taught by an inexperienced instructor without either a degree or sufficient disciplinary knowledge in biology, and with inadequate facilities and resources for laboratory work. Advanced placement or even college credit based on such courses is not appropriate.
- Use of AP and IB test scores to excuse nonbiology majors from all subject-area distribution requirements is based on the invalid assumption that AP and IB courses are generally equivalent to college-level courses. In addition, this use of AP scores undermines the concept of requiring breadth in a university-level education.

Lack of Negative Effect on Current and Potential Benefits of the AP and IB Programs

If this recommendation were implemented, none of the major benefits of the AP and IB programs to their various constituents would be lost:

- For universities, superior performance in AP or IB courses would remain a good predictor of success in college-level work.
- For schools, AP and IB courses would still represent high-profile enrichment programs that increase a school's prestige and attract better students, better teachers, and possibly additional state support.
- For teachers, AP and IB courses would still attract the best students and extra resources and would present superior opportunities for professional advancement, including higher pay and earlier promotion as elite teachers.
- For parents, AP and IB courses would continue to provide challenging academic work with the best teachers for their children, enhanced credentials for college admission and scholarship support, and college credit that could be used to shorten time to degree and hence decrease tuition costs.
- For students, AP and IB courses would continue to provide challenging academic work with the best teachers, experience with and preparation

for college-level work (assuming a qualified teacher), and enhanced credentials for college admission. And if the panel is correct, the average quality of these courses as learning experiences should become considerably better.

- For the College Board and the IBO, we surmise that since AP and IB courses and examinations would continue to benefit all of the constituents listed above, both programs would be likely to continue their growth and popularity.

In short, there would be no significant decrease in the value of AP and IB biology courses if this recommendation were implemented, and in fact the value might increase if the panel's predicted improvement in the present courses were to take place.

Prospects for Implementing This Recommendation

No organization or agency is in a position to mandate such a recommendation; universities are free to use the results of AP and IB examinations in any way they like within the constraints of state laws. However, given the enormous popularity of the AP program among its many constituencies and the increasing number of IB programs, the College Board and the IBO should have considerable leverage that could be used to promote meaningful change in high school biology education. Therefore, the panel strongly urges that:

- The College Board and the IBO discourage the use of examination scores alone for granting of automatic advanced placement out of required introductory college biology courses for science majors.
- The College Board and the IBO make clear that their assessments are designed to measure not eligibility for exemption from a specific biology course, but rather ability to succeed at college-level coursework and laboratory work in biology. Advanced placement in the form of elective credit toward a college degree is therefore appropriate, while placement out of an introductory required course for science majors is not.

SECONDARY RECOMMENDATIONS

Recommendations 4 through 14, which address specific concerns with the AP and IB programs, are reiterated below from preceding chapters in the order of their appearance. To avoid further redundancy, the chapter in which each is discussed is indicated in parentheses.

4. Students should in general not be allowed to take AP biology as a first science course in high school. A prior biology course should be

a prerequisite for AP biology, and a prior chemistry course should be strongly urged as well. In schools where the latter is impractical, chemistry should be a corequisite course. (Chapters 2 and 3)

5. Both the AP and IB curricula should be updated to include topics of major current interest in biology, such as cell signaling, development, genomics, molecular systematics, and their evolutionary implications. (Chapter 3)

6. The AP curriculum should be better balanced, with more emphasis on molecular and cell biology. The IB core topics should include more evolutionary biology. (Chapter 3)

7. The College Board should seriously consider offering two different AP biology courses, one emphasizing molecular, cellular, and developmental (MCD) and the other environmental, population, and organismic (EPO) biology, with two corresponding exams. These courses should go into depth in one of these areas of emphasis and present the basics of the other. Both courses should include a strong emphasis on evolution. (Chapter 3)

8. More curricular flexibility should be built into the AP program so that students can study fewer areas in greater depth than is possible with the current overemphasis on breadth of coverage. (Chapter 3)

9. The AP program should place more emphasis on laboratory work by developing a new and larger set of innovative, inquiry-based laboratories that conform to the *NSES* and by including more laboratory-based questions on the exam. Enough laboratories should be available so that teachers have the opportunity to select among them according to their interests and those of their students, and the laboratory-related questions on the AP exam should be general enough so that teachers have real flexibility in deciding which laboratories to offer. In addition, the AP program should include a mandatory 1-week workshop on laboratory pedagogy for beginning teachers of AP biology and should provide more ongoing laboratory training for established teachers. (Chapters 3 and 4)

10. Assessments of schools and teachers (see Recommendation 1 above) should include determination of the amount and quality of laboratory experience being provided. Scheduling of at least one 2-hour laboratory period per week should be strongly urged as a criterion for certification of an AP biology course. (Chapter 3)

11. The AP program should promote more interdisciplinary activities that relate AP biology to other academic work as well as local and regional issues. (Chapter 3)

12. The AP program should modify its assessment process to include evaluation of laboratory portfolios and other samples of stu-

dent work prior to the examination. There should also be more questions on the exam designed to test understanding of major concepts and the process of laboratory research, with less emphasis on rote memorization of facts. (Chapters 3 and 4)

13. To provide feedback, the AP program should make individual students' exam answers available to their teachers after the exams have been evaluated. (Chapter 4)

14. More attention should be paid to the interface between advanced high school and college biology teaching. In particular, more communication and collaboration should be encouraged between college and university departments and high school teachers of biology. Colleges and universities are potential sources of enrichment and resources for high school courses, and college instructors can benefit from the teaching experience of high school teachers. The need for reform is systemic. Like the AP and IB programs, colleges and universities should revise or improve introductory biology courses as necessary to bring them into line with the recommendations made in this report for high school advanced study courses. (Chapter 4)

POSSIBLE IMPACT OF THE PANEL'S RECOMMENDATIONS

Most of the panel's suggestions for improving the teaching of advanced biology in high schools are not new ideas. Why should these recommendations have more impact than similar suggestions made earlier? The panel believes several new factors substantially increase the chances for significant reform of biology teaching in the coming years.

Almost a century ago, in 1910, a committee report of the Central Association of Science and Mathematics Teachers made the following suggestions for improving biology courses (Hurd, 1961, pp. 25–26):

1. More emphasis on “reasoning out” rather than memorization.
2. More attention to developing a “problem-solving attitude” and a “problem-raising attitude” on the part of students.
3. More applications of the subject to the everyday life of the pupil and the community.
4. More emphasis on the incompleteness of the subject and glimpses into the great questions yet to be solved by investigators.
5. Less coverage of the territory; the course should progress no faster than pupils can go with understanding.

Likewise, more than a decade ago, a National Research Council (NRC) report entitled *Fulfilling the Promise: Biology Education in the Nation's Schools* addressed biology teaching and the AP program in particular (NRC, 1990). This report identified many of the shortcomings noted in the present report and made many of the same recommendations presented herein—most of which have not been implemented in the interim (see Appendix F).

As noted, however, the panel believes several recent developments have created a more favorable climate for implementation of the recommendations presented in this report:

- *National Science Education Standards* (NRC, 1996a) and its recent practical addendum, *Inquiry and the National Science Education Standards* (NRC, 2000b), are beginning to have an impact on biology teaching at all levels.
- Recent results of research on cognition and learning are becoming more widely disseminated and accepted, particularly since being made more accessible in two recent NRC reports—*How People Learn: Brain, Mind, Experience, and School* (NRC, 1999) and its practical companion volume *How People Learn: Bridging Research and Practice* (NRC, 2000a).
- The vast potential of the Internet for disseminating free information, ideas, and educational resources of all kinds to teachers and students is just beginning to be exploited.
- There is currently a general awareness among the American public that the education of the nation's scientists in particular must be improved markedly if the United States is to compete effectively in the global economy. This raised consciousness is reflected in other recent studies besides the present one; an example is the recent impressive report of the National Commission on Mathematics and Science Teaching for the 21st Century, chaired by former Senator John Glenn (National Commission on Mathematics and Science Teaching for the 21st Century, 2000).

Three solid findings about how humans learn can make a big difference if used to drive course design and teaching. The principles of adapting instruction to students' current knowledge, monitoring students' conceptual development continuously, and integrating metacognitive tasks and skills (self-assessment by students of their own levels of understanding) with active learning of science content have great potential to improve the process of education in biology as well as other sciences. The panel believes that with the above resources to back up the current efforts of reformers, it should be possible to bring about systemic changes in the way biology is taught at all levels and, in the process, to improve the effectiveness of AP and IB biology courses in the ways recommended herein.

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Appendix A

Charge to the Content Panels from the Parent Committee

Charge to the Parent Committee and Content Panels: The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines.

Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the committee's charge and study questions.

The panels should focus on the following specific issues in advising the committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facili-

tate retrieval and application in new contexts (see, e.g., *How People Learn* [National Research Council (NRC, 2000a)]).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?

2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?

3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of coverage with in-depth study of important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?

4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?

5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?

6. To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:

- a) students' mastery of content knowledge;
- b) students' understanding and application of concepts; and
- c) students' ability to apply what they have learned to other courses and in other situations.

2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience and independent investigation)?
2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The NRC's *National Science Education Standards* and the National Council of Teachers of Mathematics' *Standards 2000* propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?
2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?
3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix B

Biographical Sketches of Biology Content Panel Members

Robert A. Bloodgood is a professor in the Department of Cell Biology at the University of Virginia School of Medicine. His research focuses on mechanisms of cell motility and cell surface-cytoskeleton interactions. Using immunological, biochemical and genetic approaches, his lab examines how the movement of plasma membrane glycoproteins contributes to whole cell locomotion. In addition to his scientific research, Dr. Bloodgood has taken an unusually active interest in education. He has worked with the undergraduate education groups Coalition for Education in the Life Sciences (CELS) and Project Kaleidoscope, representing the Federation of American Societies for Experimental Biology (FASEB) and the American Society for Cell Biology. For a number of years, he was chair of the Education Committee for the American Society for Cell Biology. Dr. Bloodgood also has taken a specific interest in precollege education, as indicated by his service as a Charlottesville City School Board member and a member of the Science Education Task Force, a group of University of Virginia faculty that evaluated the science education programs in the Charlottesville Public Schools. Teacher training also has been a focus of Dr. Bloodgood's interest; for five years, he was director of a Summer Teacher Research Fellowship Award Program (funded by National Science Foundation [NSF] Teacher Enhancement and private foundation grants) that placed high school teachers in research laboratories nationwide. Dr. Bloodgood received his Ph.D. in Cell Biology from the University of Colorado at Boulder.

Mary P. Colvard is a biology teacher retired from the classroom after 31 years. She presently works as a consultant to the New York State Education De-

partment. Her excellence in teaching has been recognized through awards, such as the Radio Shack National Teacher Award, Science Teachers Association of New York State Eastern Section Service Award, Access Excellence Award, Science Teachers Association of New York State Fellow, Sigma Xi Outstanding Science Teacher, and an Outstanding Biology Teacher in New York State award. Ms. Colvard has been active in biology education at the state and national levels as well. For example, she is a leader in the National Association of Biology Teachers (NABT) and the Science Teachers Association of New York State and has participated in the Howard Hughes Medical Institute undergraduate grant directors meetings and in the National Research Council (NRC) Committee on Undergraduate Science Education. Ms. Colvard earned her M.Ed. in Secondary Biology from the State University of New York at Oneonta.

Patrick Ehrman is a retired teacher who is proposing a high school local systemic change grant (LSC) to the NSF. The LSC will service science teachers in five districts in the greater Seattle area. He has been recognized for his teaching excellence through the Shell Science Teacher of the Year Award from the National Science Teachers Association (NSTA), the Presidential Award for Excellence in Education and the NABT award for Molecular Biology Teaching. Mr. Ehrman has experience with the International Baccalaureate program as the inner city school where he taught employed it as they developed into a magnet school. Mr. Ehrman believes that inquiry-based learning is very important and established a biotechnology research program designed to attract at risk children into science.

John R. Jungck is the Mead Chair for the Sciences and a Professor of Biology at Beloit College. He also is principal investigator of the BioQUEST (Quality Undergraduate Educational Simulations and Tools in Biology) Curriculum Consortium. Dr. Jungck is a theoretical/mathematical biologist with interests in molecular evolution and science education. Dr. Jungck has long been active in education issues. He is editor of *The BioQUEST Library*, education editor of the *Bulletin of Mathematical Biology*, and on the editorial boards of several other journals. The BioQUEST Curriculum Consortium Program has brought thousands of biology educators and software developers together to produce and field test curricular materials and modules for learning long-term strategies of research. Project Kaleidoscope chose BioQUEST as a "Model Program" that works as well as other awards. His honors include an Ohaus Award for Outstanding Innovations in College Science Teaching, a Mina Shaughnessy Award, and Life Member of the Association of College and University Biology Educators. Dr. Jungck is an American Association for the Advancement of Science (AAAS) Fellow, a fellow of the National Institute of Science Education, and a former Fulbright Fellow to

Thailand. Dr. Jungck served on the NRC Committee on Information Technology in Undergraduate Science Education.

James H. Wandersee is a graduate faculty member in the Department of Curriculum and Instruction at Louisiana State University, where he is the Wm. LeBlanc Alumni Association Professor of Biology Education. His research group, the 15^o Laboratory, focuses on visual cognition, the graphic representation of biological knowledge, and visual approaches to learning biology. Trained as a botanist, Dr. Wandersee is especially interested in student and public understanding of plants, and he has served as a plant science lecturer at the Royal Botanic Gardens—Kew. He also has coauthored books on mapping biology knowledge, bioinstrumentation, teaching science for understanding, and assessing science understanding. Dr. Wandersee is a AAAS Fellow in the biological sciences section, past secretary and treasurer of the NABT, and past science program chair of the American Educational Research Association. He served for 5 years as the associate editor of the *Journal of Research in Science Teaching* and 3 years as North American Editor of the *International Journal of Science Education*. He has been recognized for his contributions to education in being named Louisiana State University's Educator of the Year and receiving LSU's first university-wide Excellence in Teaching Award. He has taught high school biology and other sciences in an urban setting for 10 years, college biology/botany for 10 years, and research-university, graduate-level, science education courses (mainly biology education courses) for 13 years.

William B. Wood (committee liaison and chair) is professor of Molecular, Cellular, and Developmental Biology at the University of Colorado, Boulder, where he formerly served as department chair. He is a member of the National Academy of Sciences (NAS), a fellow of the American Academy of Arts and Sciences, and a recipient of the NAS Molecular Biology Award. His current research focuses on the mechanisms by which cell fates and patterns are determined during embryonic development of the nematode *C. elegans*, using techniques of genetics, cell biology, and molecular biology. Dr. Wood was lead author of the widely used textbook *Biochemistry: A Problems Approach*, which helped introduce problem-based learning to biochemistry; he subsequently spearheaded the development of a graduate core course in molecular, cellular, and developmental biology that served as a model for many departments around the country. He received his Ph.D. in biochemistry from Stanford University.

Appendix C

Comparison of Specifics in the IB and AP Course Outlines and Corresponding Examination Questions

The International Baccalaureate (IB) program has a detailed course outline and prescription for the depth of teaching. While the Advanced Placement (AP) program may demand the same depth or more through its assessment, it is not clearly evident in the course outline.

Example—Cell membrane architecture:

- **IB** specifically requires teaching of the fluid mosaic model: phospholipid bilayer, cholesterol, glycoproteins, and intrinsic and extrinsic proteins. The course must include how amphipathic phospholipids maintain membrane structure, but nothing about what the intrinsic proteins are (e.g., receptors for cell signaling).
- **AP** instructs the teacher to cover the “current model of the molecular architecture of membranes.”

Example—Cell membrane transport:

- **IB** specifically requires defining diffusion and osmosis and describing passive transport, including osmosis (permeability, non- and partial permeability). IB also mandates that students be able to describe active transport across membranes, including the roles of protein carriers, adenosine triphosphate (ATP), and a concentration gradient. Students are expected to know about carrier-assisted transport and the importance of favorable concentration gradients for facilitated transport; to predict conditions for active transport with examples; to understand membrane pumps without biochemical

details; and to compare endocytosis and exocytosis, phagocytosis and pinocytosis, and vesicle-mediated transport. Students must also be able to explain the dynamic relationships among the nuclear membrane, rough endoplasmic reticulum Golgi apparatus, and cell surface membrane. They must be able to describe ways in which vesicles are used to transport materials within a cell and to the cell surface, as well as membrane proteins and their positions within membranes. (Students can use a series of diagrams to demonstrate structure relationships and how materials are moved. They must know about channel proteins and the flow of materials through channels or vesicles. Knowledge of the chemical nature of materials is not required. Mention of pores and the fact that some intrinsic proteins are anchored is also expected.) Students should be able to outline the functions of membrane proteins as antibody recognition sites, hormone binding sites, catalysts for biochemical reactions, and sites of electron carriers. (Again, nothing is included about the most important class—receptors for cell signaling—except in the oblique reference to hormone binding sites.)

- **AP** requires that students be able to detail how the structural organization of membranes provides for transport and recognition and the mechanisms by which substances cross membranes. They must also address how variations in the structure account for functional differences among membranes.

Questions on the AP and IB exams are comparable in the degree of detail expected.

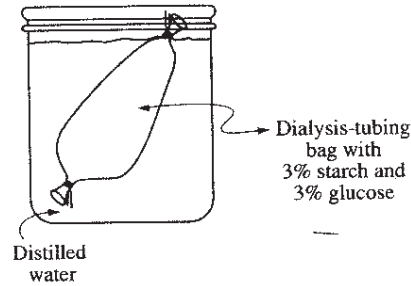
Examples—AP exam questions related to cell membranes (May 1999 exam, series of questions based on an illustration):

17. Membranes are components of all of the following except a (A) microtubule, (B) nucleus, (C) Golgi apparatus, (D) mitochondrion, (E) lysosome.

31. All of the following are typical components of the plasma membrane of a eukaryotic cell except (A) glycoproteins, (B) cytochromes, (C) cholesterol, (D) phospholipids, (E) integral proteins.

61. Which of the following cellular processes is coupled with the hydrolysis of ATP? (A) Facilitated diffusion, (B) Active transport, (C) Chemiosmosis, (D) Osmosis, (E) Na^+ influx into a nerve cell.

Questions 114–116 refer to an experiment in which a dialysis-tubing bag is filled with a mixture of 3 percent starch and 3 percent glucose and placed in a beaker of distilled water. After 3 hours, glucose can be detected in the water outside of the dialysis-tubing bag, but starch cannot.



114. From the initial conditions and results described, which of the following is a logical conclusion? (A) The initial concentration of glucose in the bag is higher than the initial concentration of starch in the bag. (B) The pores of the bag are larger than the glucose molecules but smaller than the starch molecules. (C) The bag is not selectively permeable. (D) A net movement of water into the beaker has occurred. (E) The molarity of the solution in the bag and the molarity of the solution in the surrounding beaker are the same.

115. Which of the following best describes the conditions expected after 24 hours? (A) The bag will contain more water than it did in the original condition. (B) The contents of the bag will have the same osmotic concentration as the surrounding solution. (C) Water potential in the bag will be greater than water potential in the surrounding solution. (D) Starch molecules will continue to pass through the bag. (E) A glucose test on the solution in the bag will be negative.

116. If, instead of the bag, a potato slice were placed in a beaker of distilled water, which of the following would be true of the potato slice? (A) It would gain mass. (B) It would neither gain nor lose mass. (C) It would absorb solutes from the surrounding liquid. (D) It would lose water until water potential inside the cells is equal to zero. (E) The cells of the potato would increase their metabolic activity.

Essay: Communication occurs among cells in a multicellular organism. Choose three of the following examples of cell-to-cell communication, and for each example, describe the communication that occurs and the types of responses that result from the communication.

- Communication between two plant cells.
- Communication between two immune cells.
- Communication either between a neuron and another neuron or between a neuron and a muscle cell.
- Communication between a specific endocrine gland cell and its target cell.

Examples—IB questions related to cell membranes:

[November 1999 Paper One (multiple choice), #2]:

2. The cells of plant roots can take up ions from the soil against the concentration gradient. What is the process used? (A) Osmosis. (B) Passive transport. (C) Diffusion. (E) Carrier-assisted transport.

[November 1999 Paper Two]:

Part A (Extended Response) #2 A. Draw the structure of a nephron. B. Identify where most active transport occurs and identify one specific location where active transport occurs in plants. C. Define water potential. D. Explain the process of water uptake in roots by osmosis. E. List three abiotic factors which affect the rate of transpiration in a typical terrestrial mesophytic plant.

Part B (Extended Response) A. List three functions of lipids. B. Outline the production of ATP by chemiosmosis in the mitochondrion. C. Explain the process of muscle contraction.

Appendix D

Laboratory Experience in AP and IB Biology Courses

The AP manual (Educational Testing Service, 1999) suggests “since one-fourth to one-third of the credit in comparable college courses is derived from laboratory work, AP courses should likewise emphasize laboratory work.” There are 12 recommended laboratory exercises:

- Lab 1—Diffusion and Osmosis
- Lab 2—Enzyme Catalysis
- Lab 3—Mitosis and Meiosis
- Lab 4—Plant Pigments and Photosynthesis
- Lab 5—Cell Respiration
- Lab 6—Molecular Biology
- Lab 7—Genetics of Organisms
- Lab 8—Population Genetics and Evolution
- Lab 9—Transpiration
- Lab 10—Physiology of the Circulatory System
- Lab 11—Animal Behavior
- Lab 12—Dissolved Oxygen and Aquatic Primary Production

The AP laboratories are not inquiry based and involve little instrumentation. The write-up varies from laboratory to laboratory and involves primarily filling in the data table and/or blanks along with providing some “short” extended responses. There is no external check on whether the laboratories are completed.

An example is AP Lab 6, Molecular Biology. Lab 6a demonstrates bacterial transformation using *E. coli* and the pAMP plasmid. Students are given a step-by-step procedure. The analysis consists of four questions: #1 is a cell count; #2 is a comparison; #3 leads students through a calculation of the transformation efficiency; and #4 is open ended and asks students to discuss factors influencing transformation efficiency. Lab 6b is called “Restriction Enzyme Cleavage of DNA and Electrophoresis.” Students are told to conduct

the lab following directions provided either by their teacher or by the kit they are using. Students do not perform their own digest; they merely load DNA that has been digested for them. They are provided with a photo of a gel carrying size markers and asked to represent graphically the relationship between migration rate and fragment length. They then analyze their own gels to determine the size of their fragments by measuring the migration rates.

The IB program requires that 25 percent of the teaching hours “be spent following an internally assessed scheme of practical/investigative work, related to all aspects of the program including the options.” The subject and design of the labs are at the teacher’s discretion. These are used to create a portfolio and must be written using a specified format. The “criteria” are as follows:

Planning (a)	Defined problem(s), research question(s); formulated hypothesis(es); selected any relevant variables.
Planning (b)	Designed realistic procedures to include appropriate apparatus, materials, methods for both the control of variables and collection of data.
Data collection	Observed and recorded raw data with precision and presented them in an organized way (<i>using a range of appropriate scientific methods/techniques</i>).
Data analysis	Transformed, manipulated and presented data (<i>in a variety of appropriate ways</i>) to provide effective communication.
Evaluation	Evaluated the result(s) of experiment(s) and evaluated procedure(s); suggested modifications to the procedure(s), where appropriate.

A summative evaluation is done of the following three skills:

Manipulative skills	Carried out a range of techniques proficiently with due attention to safety; followed instructions.
Personal skills (a)	Worked within a team; recognized contributions of others; encouraged the contributions of others.
Personal skills (b)	Approached experiments/investigations/projects and problem-solving exercises with self-motivation and perseverance and in an ethical manner; paid due attention to the environmental impact.

The portfolio accounts for 24 percent of the student’s final grade, derived from the internal assessment by the teacher. The teacher grades both

the Group 4 project (interdisciplinary investigation) and the labs, which together constitute the portfolio.

IB teachers are required to submit a description (“practical scheme of work”) of laboratory work done in their class to an external examiner. The examiner moderates the overall practical scheme of work experienced by the students and provides feedback to teachers and schools on their compliance with the IBO internal assessment requirements. Portfolios from individual students are sampled by the examiners to enhance standardization of grades across the program.

There is no laboratory in the IB program that is directly comparable to the above AP example. Teachers may select any molecular genetic activities they wish. However, teachers are provided with an “inquiry template” that specifies what components a laboratory should include. Recommended components are Background Information, Question/Hypothesis, Design/Procedure, Data Collection, Data Analysis, Evaluation, and Manipulative and Personal Skills. Students are charged to work collaboratively but with individual accountability and to pay attention to the ethical and environmental implications of the investigation. Not all laboratories must include all the above components, but each component must be assessed twice during the course (and teachers are encouraged to “address” each component multiple times).

Appendix E

Some Useful Web Sites for Advanced Biology Courses

For obvious reasons, no listing of such sites can be complete, as the Web resources relevant to biology teaching are expanding daily. Presented below is a sampling of useful sites known to the panel as of this writing. Simple searches by readers will turn up many additional valuable resources.

American Association for the Advancement of Science (AAAS):

<http://aaas.org/>

Association of Science and Technology Centers:

<http://www.astc.org/>

BioQUEST Curriculum Consortium:

<http://bioquest.org>

Biological Sciences Curriculum Study

<http://www.bsccs.org>

Cornell Math and Science Gateway:

<http://www.tc.cornell.edu/Edu/MathSciGateway/>

Discovery:

<http://www.discovery.com/>

Edvotek (The Biotechnology Education Company)

<http://www.edvotek.com>

Entrez

<http://www.ncbi.nlm.nih.gov/Entrez>

Instructional Materials in Science Education:

<http://www.ncsu.edu/imse/>

Microscopy Primer:

<http://micro.magnet.fsu.edu/primer/index.html>

National Association of Biology Teachers:

<http://www.nabt.org>

National Center for Biotechnology Information

<http://www.ncbi.nlm.nih.gov>

National Sciences Teachers Association:

<http://www.nsta.org>

National Science Education Standards:

<http://www.nap.edu/catalog/4962.html>

Teaching about Evolution and the Nature of Science:

<http://www.nap.edu/catalog/5787.html>

National Science Foundation Student Summer Opportunities:

<http://www.ehr.nsf.gov/ehr/esie/studentops.htm>

National Science Foundation Teacher Enhancement Summer Opportunities:

<http://www.ehr.nsf.gov/ehr/esie/teso/>

Exploratorium:

<http://www.exploratorium.edu>

Eisenhower National Clearinghouse:

<http://www.enc.org>

Lawrence Hall of Science:

<http://www.lhs.berkeley.edu>

Access Excellence:

<http://www.gene.com/ae>

Cells Alive:

<http://www.cellsalive.com>

National Center for Biotechnology Information:

<http://www.ncbi.nlm.nih.gov>

The On-Line Biology Book:

<http://gened.emc.maricopa.edu/bio/bio181/BIOBK/BioBookTOC.html>

Appendix F

Conclusions and Recommendations from the 1990 NRC Report Fulfilling the Promise: Biology Education in the Nation's Schools

(1) “We are concerned that the AP biology course has been modeled on introductory college biology courses that for many students are notoriously poor educational experiences. The time has come to stop designing curricula by the process of serial dilution, in which the high school course is a thin version of the college course, and the middle school course is a thin version of the high school course.” (p. 85)

(2) “... [s]erious problems, both philosophical and practical, attend the AP biology program” (p. 85). To paraphrase:

- Covers too many aspects of biology in too short a time.
- Requires “teaching to the examination.”
- Diverts academically able students from other high school courses to a college-level focus.

(3) We are skeptical whether AP biology is commonly able to provide an exposure equivalent to that offered in most colleges” (p. 86).

(4) The report therefore made recommendations (pp. 86–87):

- **A consensus needs to be reached as to what the AP biology course should be. The present policy of modeling the AP course after a composite view of college courses is missing opportunities for generating a unique high-school experience, providing a more realistic introduction to experimentation, and providing better college preparation. Although the recent inclusion of quantitative experimenta-**

tion in the AP Program was needed and is commendable, an introductory college course may not be the soundest educational experience for students who have time for a second course in biology in high school. Whether the AP course will develop into a strong component of biology education or will itself become an obstacle to reform is unclear. A national body of educators, high-school and college biology teachers, and scientists should make specific recommendations about the AP curriculum, examination, and college credit. (See also Chapter 8.) The College Board should be asked to study fully its own record of success, follow up on the college placement of students, and assess compliance of high schools with its recommendations for prerequisites.

- Whatever their form, AP or other advanced biology courses should not be taken instead of chemistry, physics, or mathematics. Nor should they become the “honors” section, taken in lieu of the first high-school course in biology. The AP biology course should be taken as late in high school as possible, preferably in the senior year, to enable the subject to be taught as an experimental science to students whose maturity is close to that of college freshmen. Even a properly designed AP course in biology is inappropriate for younger students and for those without maximal preparation in mathematics and the physical sciences.

- We suggest that the terminal-year AP biology course provide intensive treatment of a few topics in molecular biology, cell biology, physiology, evolution, and ecology. Emphasis should be on experimental design, experimentation and observation, data analysis, and critical reading. Thus, the course cannot be modeled after existing college courses, which broadly cover all biology. Engaging students in direct investigations of natural phenomena without attempting to “cover” the subject matter of the introductory college biology course is judged by this committee to be more educationally sound than the current program. A rigorous examination devoted to problem solving that requires the application of biological concepts should accompany such a revision.

- This course should be taught only by teachers both capable of providing a sophisticated and broad knowledge of biology and having the ability, training, experience, resources, and time to oversee an independent experimental approach. For example, a teacher who has not had first-hand experience in independent research should not be assigned to teach AP biology. Specific inservice training and certification should be used to ensure that only qualified teachers teach the AP course. The College Board should take initiatives to see that the program meets those more demanding specifications, but school

administrators must understand and cooperate as well. If AP science courses are to be offered, there should be a line item in the school budget to support them, and they should not be given at the expense of regular science laboratory activities.

- **The premise that AP courses provide college credit is not necessarily flawed; however, the nature of what the credit is for needs examination. A second course giving instruction in scientific reasoning, based on experimental design, and using sophisticated physical, chemical, and mathematical, as well as biological, principles would in fact provide better preparation for college than the present broad review. Colleges and high schools should both recognize the value of a second course in *experimental* science taken at the end of high school. Such a course need not be sponsored by the College Board or be designated “advanced placement.”**

Content Panel Report: Chemistry

Introduction

The National Research Council's Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed a chemistry panel to compare and evaluate the Advanced Placement (AP), the International Baccalaureate (IB), and alternative programs for advanced study in chemistry with respect to their pedagogy, content, assessments, and outcomes (the charge to the panel is presented in Appendix A). The chemistry panel met twice (in June and July 2000) to address its charge from the parent committee. The panel was chaired by a member of the parent committee, who served as liaison to the committee and consolidated the panel's findings and recommendations into this report. Panel members also included high school chemistry teachers with AP, IB, and New York State Regents examination experience, along with experienced college and university chemistry professors noted for their work in chemical education (for biographical sketches, see Appendix B).

Neither independent researchers nor the AP or IB program has published systematic data about the programs. Thus few data on the ways in which AP and IB courses are actually implemented in U.S. high schools, the long-term consequences to students who take AP or IB courses, or the effects of an increasing number of students who arrive at college with multiple AP and IB credits to use toward advanced placement or to meet graduation requirements were available to the panel. Because important data about the programs have not yet been published by either the programs or independent researchers, the panel focused its analysis on what the programs say they do, using available program materials such as course guides, released examinations, teacher manuals, program goals, and mission statements.

The chemistry panel carefully reviewed a substantial volume of background materials related to the AP and IB programs; those materials are listed in Appendix C. The findings and recommendations reached by the panel and presented in this report were consensus opinions, arrived at by reading the background materials and holding extensive discussions. Panel

members also contributed written materials that were incorporated into this final report.

The remainder of this report is divided into four chapters. Chapter 2 presents an overview of advanced study in chemistry for high school students. Chapters 3 through 5 respond to the questions under the panel's charge. Chapter 3 focuses on the students who enroll in the AP chemistry course and the IB program, what is taught and how well it is being taught, the grade levels at which these advanced courses are offered, and the background and prerequisites needed to take and succeed in the courses. Chapter 4 addresses those who teach AP and IB chemistry courses, including their academic preparation, credentials, and appropriateness for the task. Chapter 5 provides an analysis of the assessments and outcomes associated with the AP chemistry course, the IB chemistry program, and their affiliated examinations. Throughout these chapters, key findings appear in *italic type*. The report concludes in Chapter 6 with a summary and recommendations regarding the AP chemistry course and the IB program, including the panel's consideration of whether advanced study options in high school should be associated with opportunities for students to earn college or university credit.

2

Overview of Advanced Study Programs in Chemistry in U.S. High Schools

CHARACTERISTICS OF AP CHEMISTRY

In addition to recommending that at least 290 minutes per week be allotted to Advanced Placement (AP) chemistry courses, the College Board characterizes the AP chemistry course as follows:

The AP chemistry course is designed to be the equivalent of the general chemistry course usually taken during the first college year. For some students, this course enables them to undertake, as freshmen, second-year work in the chemistry sequence at their institution or to register in courses in other fields where general chemistry is a prerequisite. For other students, the AP chemistry course fulfills the laboratory science requirement and frees time for other courses.

AP chemistry should meet the objectives of a good general chemistry course. Students in such a course should attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course should contribute to the development of the students' abilities to think clearly and to express their ideas, orally and in writing, with clarity and logic. The college course in general chemistry differs qualitatively from the usual first secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by the students. Quantitative differences appear in the number of topics treated, the time spent on the course by students, and the nature and variety of experiments done in the laboratory. *Secondary schools that wish to offer an AP chemistry course must be prepared to provide a laboratory experience equivalent to that of a typical college course* (College Entrance Examination Board [CEEB], 1999a, p. 1).¹ (Note: Italics added for emphasis by the College Board.)

¹These publications are commonly referred to as *Acorn Books* because of the distinctive logo on their covers.

Thus by design, AP chemistry courses (and all other AP courses) are modeled after typical college-level introductory courses in the discipline. As a result, these high school courses are supposed to follow trends in college-level introductory general chemistry (not introductory chemistry, which typically denotes remedial or nonscience major chemistry courses).

The College Board goes on to say that:

The AP chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry. A survey of students who took the 1986 AP Chemistry Examination indicates that the probability of achieving a grade of 3 or higher on the AP Chemistry Examination is significantly greater for students who successfully complete a first course in high school chemistry prior to undertaking the AP course. Thus it is strongly recommended that credit in a first-year high school chemistry course be a prerequisite for enrollment in an AP chemistry class. (CEEB, 1999a, p. 1)² (Note: Italics added for emphasis by the College Board.)

Whether schools offering AP courses follow this recommendation probably depends on local practice. In any case, the *chemistry panel unanimously agrees that, unless truly exceptional circumstances dictate, students should not take advanced chemistry as their first chemistry course in high school.*³ Although the College Board also recommends against this practice, it does happen, and the panel believes it is detrimental to the student, who is academically short changed by such circumstances. It is in the first course that the requisite concepts are learned and the laboratory skills developed that are needed to legitimize advanced study in the second high school chemistry course.⁴

An appropriate background in mathematics is needed to succeed in AP chemistry, and the College Board addresses this matter as well: "*In addition, the recommended mathematics prerequisite for an AP chemistry class is the*

²The College Board (2001b) reports that in 2001 of the 55,000 students taking AP Chemistry, 3,000 were in the ninth or tenth grades, and 28,000 were in the eleventh grade. However, it is unclear from these data what percentage of students take AP Chemistry as their first course in the subject. Of the 28,000 students in the eleventh grade taking AP Chemistry, it is possible that many or most of them took introductory chemistry in the tenth grade. Additional research is needed to determine the actual proportion of students who take AP Chemistry as their first course in the subject.

³Exceptional circumstances that would enable some students to succeed in an advanced course in chemistry as their first exposure to the discipline could include students who have had unusual preparation in science and mathematics or who have proven that they can acquire the concepts taught in introductory chemistry on their own. The panel emphasizes that such exceptions would be made only in very rare cases.

⁴There are few data on the extent to which this practice occurs. The panel believes that gathering such data is important and calls on the College Board to gather and publish data describing the ways in which their courses are implemented in schools and the effects of those courses on student learning and achievement.

successful completion of a second-year algebra course" (CEEB, 1999a, p. 1). (Note: Italics added for emphasis by the College Board.)

The College Board also is explicit regarding the place of AP chemistry in the total science curriculum: "The advanced work in chemistry should not displace any other part of the student's science curriculum. It is highly desirable that a student have a course in secondary school physics and a four-year college preparatory program in mathematics" (CEEB, 1999a, p. 2).

Because of the structure of the AP program, the AP chemistry course can be a stand-alone course offered by a high school in the absence of any other AP course offerings at that high school or other high schools in the district. Moreover, students who enroll in and complete AP chemistry, or any other AP courses, are not required by the College Board to take the AP examination developed by the College Board and administered by the Educational Testing Service.⁵

Administered each May, the AP chemistry examination takes 3 hours and consists of 2 sections. The first section (90 minutes) consists of 75 multiple-choice questions and represents 45 percent of the final grade. The College Board uses some common multiple-choice questions from year to year as a consistency check on the performance of the students taking the exam. The second section of the examination (also 90 minutes) represents 55 percent of the final grade and consists of several short-answer and essay-style questions that purportedly provide for a more in-depth assessment of students' understanding of chemistry principles. The questions may require calculations, a short essay response, or the determination of reaction products. Section II contains both required questions to which all students must respond and opportunities for students to choose two of four additional questions that they think they are best prepared to answer.⁶ The examinations are collected and sent to a central location, where they are graded by a national team of graders.⁷ All of the examinations are graded during a 1-week period. The College Board has developed procedures to ensure uniformity in the scoring process.⁸ The AP score (1–5) is determined by a complex formula that factors in how well others who took the test performed, how scores were distributed over the past 3 years, and how well college

⁵Although the College Board has no such requirement, some state and local school districts are now requiring students to take the examination. In these circumstances, the district or state sometimes pays for part or all of the costs to students of taking the exams.

⁶For example, in 2001 the AP Chemistry examination required that students answer questions 1, 4, 5, and 6 and allowed them to choose between questions 2 and 3 and between questions 7 and 8.

⁷Graders are drawn from a pool of experienced high school AP teachers and college faculty with expertise in the discipline. Individuals are nominated or apply to become graders.

⁸For example, more than one grader reads each paper, and large discrepancies between assigned scores are resolved by third and sometimes fourth readers.

students at the end of their introductory course performed on the AP examination.

CHARACTERISTICS OF THE IB PROGRAMME AND IB CHEMISTRY

Whereas the AP program is a collection of individual, unrelated courses, the International Baccalaureate (IB) Diploma Programme is a comprehensive 2-year curriculum consisting of six academic areas.⁹ IB courses may be taken at either the Standard Level (SL) or Higher Level (HL).¹⁰ Chemistry is included with Group 4, the Experimental Sciences. IB Diploma candidates must take one subject from each of the six subject areas, with at least three and not more than four being HL. The other courses taken are SL. Thus, a chemistry student can take either the HL or SL version of the IB chemistry course and related examination. IB students are permitted to take two science subjects simultaneously from Group 4.

Students can and do take individual IB courses without working toward an IB Diploma. These students are known as certificate candidates, as opposed to diploma candidates. Only diploma candidates are required to take one subject from each area, as well as to fulfill additional requirements. Approximately 65 percent of IB students work for and complete the requirements for a diploma.

IB Diploma candidates must also complete three other requirements: (1) the interdisciplinary Theory of Knowledge course; (2) an extended essay of approximately 4000 words; and (3) participation in the school's Creativity, Action, Service (CAS) program involving sports, artistic pursuits, and community service work. Unlike the AP program, the IB program seeks to provide interdisciplinary preparation for university work rather than attempting to meet particular university course requirements, although strong perfor-

⁹Although AP courses are not traditionally offered as an integrated program, the panel notes that for several years the College Board has offered an International Diploma for Advanced Placement. This program is designed for students who plan to pursue undergraduate studies outside the United States or Canada. The total number of students seeking this diploma is relatively small. To earn the diploma students take four AP courses in three different subject areas and must receive an average grade of 3 or higher. In 2000, the College Board initiated a pilot test of a new AP Diploma that is similar to the IB Diploma in many respects. To qualify for this diploma, students must take one AP course from each of the following areas: languages and literatures, sciences, mathematics, history, and social sciences. They must also take one additional AP course in any area. In addition, students must earn an average grade of 3 on all exams taken. Additional information is available at http://www.collegeboard.org/ap/students/benefits/int_diploma.html [4/24/02].

¹⁰SL courses entail 150 hours of class time, while HL courses require 240 hours. HL courses are generally taught over 2 years.

mance in IB courses is used to grant advanced placement at colleges and universities (International Baccalaureate Organisation [IBO], 1999).

All Group 4 subjects include required practical (laboratory) work, which makes up a significant portion of the course.¹¹ Although this laboratory work focuses primarily on the assessment of laboratory skills, it also offers opportunities for students to perform experiments and experience first-hand the benefits and limitations of scientific methodology. Individual teachers plan the Practical Scheme of Work (PSOW) for students in their classes. Thus, the laboratory experiences of students in different IB classrooms will vary. The PSOW should represent the breadth and depth of the subject syllabus, but students are not required to conduct an investigation for each topic in the syllabus. To ensure quality and to foster improvements, teachers are required to submit copies of their PSOW annually to the IBO for moderation and feedback.

As noted above, the College Board recommends that at least 290 minutes per week be allotted for an AP chemistry class (174 total hours per year, assuming a 36-week academic year). Of this total, 54 hours is recommended for laboratory work. By comparison, IB recommends a total of 240 hours for HL and 150 hours for SL courses per academic year. Of this time, it is recommended that 60 hours for HL courses and 40 hours for SL courses be devoted to investigative activities that, along with the Group 4 project, comprise the internal assessment (IA) component of the course.

A common core curriculum applies to both HL and SL chemistry courses. The core material taken by SL students is a subset of the HL program. At the SL level, the core topics make up about 60 percent of the material, while at the HL level the core represents 75 percent of the covered topics. Both SL and HL students also study optional topics that their teacher selects from among a list of topics included in the course syllabus. SL students study three options of 20 hours each, while HL students study two options of 30 hours each chosen by the school. The only option available exclusively to SL students is higher physical organic chemistry (15 hours). Options available to both SL and HL students (15 and 22 hours, respectively) include medicines and drugs, human biochemistry, environmental chemistry, chemical industries, and fuels and energy. The options available to HL students only (22 hours) are modern analytical chemistry and further organic chemistry. Additional hours of internally assessed practical work are required for both SL and HL options.¹² Further, both SL and HL students must spend 10–15

¹¹The IBO recommends that 25 percent of the course be devoted to practical (laboratory) work.

¹²SL options require an additional 5 hours of practical work that is internally assessed; options that are suitable for both SL and HL require an additional 5 hours for SL students and 8 hours for HL students; and options exclusively for HL students require 8 hours of internally assessed practical work.

hours on an interdisciplinary Group 4 project, which is a common element of all IB science programs and constitutes 10 hours of the internally assessed practical scheme of work.¹³

The IB chemistry examination is given annually and is taken at either the SL or HL, depending on the student's course of study. The SL exam consists of three papers. The first paper (0.75 hour) consists of 30 multiple-choice questions. The second paper (1 hour) contains short-answer questions and brief calculations in Part A and offers students a choice of answering one of two more extended questions in Part B. The remaining paper (1.25 hours) consists of one or two questions based on the course options completed by an individual student. The HL examination also comprises three papers with the same distribution as that of the SL examination but with topics examined in greater depth. The time allotted for the first HL paper is 1 hour, for the second 2.25 hours, and for the third 1.25 hours.

IB examinations are sent to examiners around the world who mark and return them to the IBO offices in Cardiff, Wales. During the grading process, examiners measure each student's performance against seven grade descriptors, given in the form of levels of performance that candidates can demonstrate on the examination. To ensure uniformity in the grading across examiners who are not centrally located, a representative sample of graded examinations from individual examiners is sent to the chief examiner for moderation. IB examination grades (1–7) are based on established criteria that represent an *absolute standard* of quality; thus, the interpretation of a student's performance is criterion referenced. A grade of 7 represents "excellent performance," while grades of 4 and 1 represent "satisfactory" and "very poor" performance, respectively. All IB group subjects, including chemistry, have a significant IA component involving laboratory work and a project, which constitutes 24 percent of a student's final grade. The IA component is internally assessed at the student's school by the teacher and is also externally moderated by the IBO. Final IB scores for each student are a combination of the results of the IA and the external scoring of the examination papers but are reported to the school as a single total.

QUALIFICATIONS FOR TEACHING ADVANCED HIGH SCHOOL COURSES IN CHEMISTRY

To provide a chemistry course consistent with the criteria noted above for an advanced study course in chemistry at the high school level, those

¹³The Group 4 project is an interdisciplinary activity that involves all of the IB science students at the school in identifying and investigating an issue, usually of local interest. The project requirements emphasize sharing concepts and theories from across the disciplines and the processes involved in scientific investigation, rather than producing products.

who teach such a course must be adequately prepared. *The chemistry panel takes this to mean a B.S. or B.A. degree in chemistry and preferably an M.A. or M.S. degree in chemistry.* The preparation of AP and IB chemistry teachers is discussed in detail in Chapter 4.

DEFINITION OF ADVANCED STUDY IN CHEMISTRY FOR HIGH SCHOOL STUDENTS

The chemistry panel agrees that the prerequisite first-year high school course in chemistry should provide students with an introduction to the atomic-scale view of matter, including its connection to macroscopic physical and chemical properties and to the language used to express these relationships, using the periodic table as an organizing entity. Moreover, as befits the nature of chemistry as an experimental science, the introductory (first-year) course should include experimentation and the use of scientific methodology.

Members of the panel also agree that *any* high school course in chemistry that is labeled as advanced study, whether or not it is structured according to an established curriculum and assessment such as AP or IB, should enable students to develop the ability to explore the chemistry concepts and laboratory practices introduced in the first-year course in greater depth and, where appropriate, to conduct some form of research. Under the guidance of a qualified advanced study instructor, desirable features of such advanced study would include some combination of the following characteristics:

- Application of basic ideas to more complex materials, systems, and phenomena
- Use of modern instrumentation, methods, and information resources
- Integration of concepts within and between subject areas, including extensions to other disciplines
- Use of appropriate mathematical and technological methods
- Extended use of inquiry-based experimentation
- Development of critical thinking skills and conceptual understanding
- Use of appropriate tools for assessing student performance and attitude that reflect current best practices
- Promotion of communication skills and teamwork

These characteristics are consistent with visions for undergraduate education articulated in the National Science Foundation's (NSF) *Shaping the Future* (1996) and the National Research Council's *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (1999) reports. These two reports summarize what undergraduate science, mathematics, engineering, and technology courses, including introductory courses

in chemistry, should encompass if they are to serve the dual objectives of enhancing scientific literacy and providing adequate preparation for a diverse, talented technical workforce.

Catalyzed by programs sponsored by NSF, the American Chemical Society, and other organizations concerned with improving undergraduate science education, some college and university chemistry courses are being revamped to achieve the objectives that those reports recommend (see, e.g., *ChemConnections*,¹⁴ *Chemistry: Structure and Dynamics* [Bodner, Rickard, and Spencer, 1999]; Landis and Peace [1998]; *The Chemical World: Concepts and Applications*, 2nd edition [Moore, Stanitski, Wood, Kotz, and Joest, 1998]; and the *Discovery Chemistry* curriculum developed at the College of the Holy Cross¹⁵). However, many faculty who oversee undergraduate programs in chemistry have not yet confronted and addressed these issues.

FINDINGS AND CONCLUSIONS

Although exceptions exist among schools and teachers, *the chemistry panel finds that in general the material taught in advanced courses (as specified in the guidebooks provided by the College Board and the IBO) fail to meet many of the criteria outlined in the previous section.* In addition, the panel finds the AP and IB final examinations to be formulaic and predictable from year to year in their approaches and question formats. Thus, with sufficient practice in taking such examinations and enough drill on the major concepts that the examinations are likely to test, students can score well primarily by rote, without actually understanding the major concepts associated with the topics being tested.

The panel also agrees that laboratory work should be a significant component of an advanced chemistry course, and assessment of laboratory skills should be a major part of the final examinations. However, the examinations reviewed for this study led the panel to conclude that the AP and IB final examinations do not adequately test understanding of laboratory techniques or the interpretation of laboratory data. In fact, it was only recently that the College Board added a question to the AP assessment that purportedly tests laboratory-based knowledge and skills. The panel notes that the final IB examination does emphasize laboratory-based knowledge and skills through assessments other than the final examination. For example, the IBO recommends that 25 percent of the time in the course be spent on investigations and projects and that 24 percent of the final grade be awarded for this component. Additionally, all IB science examinations contain a required data analysis question on the second paper.

¹⁴<http://mc2.cchem.berkeley.edu/> [4/23/02].

¹⁵<http://www.holycross.edu/departments/chemistry/discovery/> [4/23/02].



Quality and Content of the Learning Experience for Students

MOTIVATION FOR TAKING ADVANCED COURSES IN HIGH SCHOOL

The motivation to take an Advanced Placement (AP) or International Baccalaureate (IB) chemistry course comes from a wide range of external as well as internal sources. Some students simply enjoy science, and such courses offer the opportunity to learn about chemistry in greater depth than is offered by a first-year course. Other students may want to take the most rigorous program of studies offered by their high school (with less regard for the specific courses taken); others may want to develop an academic profile that is sufficiently competitive to gain admission to highly selective colleges. Still others may enroll more from parental or peer pressure than from a real desire to undertake a second course in chemistry. Students and parents increasingly may see the completion of these courses as a way to enhance a student's transcript when applying for college admission (College Entrance Examination Board [CEEB], 1994). Parents may also believe that students in AP and IB courses have access to better teachers and more resources and that the atmosphere will be more academically focused than in other courses.

Completing an AP chemistry course and passing the examination at the minimum level designated by individual colleges and universities may make a student eligible to earn college course credit, to place out of first-semester or first-year college chemistry, or to receive credit for completion of a general education or distribution requirement in science. Depending on the options available at the receiving institution and which option is selected, a student may be able to reduce the amount of matriculation time required for a degree, thereby saving tuition and other fees. Likewise, although the IB program was not designed to offer students opportunities for college credit,

increasing numbers of colleges and universities are now offering such credit to IB students who have earned specified scores.¹⁶

IMPACT OF ADVANCED CHEMISTRY COURSES ON THE CURRICULUM

The availability of a selection of AP courses, including AP chemistry, provides opportunities for students to extend their knowledge and academic skills beyond those required by first-tier courses. Despite these advantages, however, the existence of AP courses can also create curricular difficulties. The AP program of courses can have two negative effects on the overall high school science curriculum.¹⁷ The first of these is compression of that curriculum. Although there is variation among schools, the first-year chemistry course has generally been offered during the junior year. However, schools offering a range of AP science courses have helped foster a national shift toward offering biology to ninth-grade students and chemistry to tenth-grade students so the final 2 years of high school can be used for advanced work, including AP chemistry. Alternatively, this shift allows for making physics available in the eleventh grade, thereby offering opportunities to focus on advanced work in the twelfth grade. The panel believes that such a shift does not coincide well with the academic preparation and intellectual skills of high school freshmen and sophomores and therefore believes that the science concepts being taught may be too abstract for the age of many students at that level.

Curriculum compression may also prevent students from being able or electing to take the full range of first-year courses in science (biology, chemistry, and physics) during their high school years. Such students may substitute AP biology or AP chemistry for first-year physics, thereby leaving them with significant lacunae in their quantitative understanding of physical science concepts. This practice is contrary to the College Board's recommendation (CEEB, 1999a, p. 2). Moreover, those who take first-year chemistry as sophomores but elect not to take AP chemistry in their junior or senior year have a 2-year hiatus between their study of high school chemistry and the time at which they enter college and major in a discipline requiring them to take general chemistry. This time lag, extended in chemistry by 1 year be-

¹⁶If a particular college requests help, the International Baccalaureate Organisation (IBO) will work with the institution to develop appropriate policies related to credit and placement decisions that are based on IB examination scores (see, <http://www.ibo.org> [4/24/02]).

¹⁷The issues associated with compression of curriculum are discussed in detail in Chapter 10 of the parent committee's report. The present discussion serves only to raise the issue as it may pertain to chemistry.

cause of curriculum compression, can cause difficulty for some students in making the transition from high school to college chemistry.

Advanced mathematics is the gateway to advanced science, particularly advanced chemistry and physics. The College Board recommends that students taking AP chemistry previously have completed 2 years of algebra and 1 year of geometry in addition to having taken the first-year chemistry course. To take AP chemistry as a junior, a student must complete these mathematics prerequisites by the end of the sophomore year. Thus, these mathematics requirements also compress the mathematics curriculum. The result is that Algebra I must be completed in eighth grade. Given the small percentage of minority and rural youth who either have access to or enroll in Algebra I in grade 8, the need to have completed these courses by the end of grade 10 in effect sets up a de facto homogenous grouping of students that continues throughout the 4 years of high school. Such tracking has serious implications with regard to which students are able to take advantage of advanced courses in chemistry and other sciences and thereby raises issues of access and equity with regard to the benefits of college admission, credit, and placement that currently accrue to students who have such opportunities for advanced study (see Chapters 2 and 10 in the parent committee's report for more discussion of these issues).

COURSE CONTENT

The IB curriculum, in some sense, flanks the AP course, with expectations that are either higher or lower than those for AP chemistry. The IB Standard Level (SL) course is at a lower level than AP with respect to the content coverage; the IB Higher Level (HL) course is at a somewhat higher level than AP in terms of the topics discussed, especially in light of the HL options. The AP curriculum deals in greater depth than IB with concepts related to kinetic molecular theory, chemical kinetics, and equilibrium. In contrast, the IB curriculum at least introduces concepts from organic chemistry, an area generally not included in the AP course. The IB courses also provide students with some opportunities to develop conceptualizations of the material presented; most such opportunities are lacking in AP courses. In IB courses, chemical concepts are often taught within a context, and examination questions are designed to assess several aspects of a concept, not merely one or two. To cite one example, enthalpy changes in solution are linked to thermal changes, as well as experimental design and sources of error. Bond dissociation energies are associated with environmental changes such as stratospheric ozone depletion. In these aspects, the IB course is broader in content and outlook than its AP counterpart. A comparison of the differences between the two approaches is summarized in Table 3-1.

TABLE 3-1 Comparison of AP and IB Chemistry Courses

AP	IB
1 level	2 levels: SL or HL
1 year	1 or 2 years for SL; 2 years for HL
Less conceptualization of topics	Deeper conceptualization of topics
Molecular-level interpretation of KMT (kinetic molecular theory)	More descriptive (macroscale) approach to KMT
More quantitative treatment of kinetics and equilibrium	Less quantitative treatment of kinetics and equilibrium, but better conceptualization of the topics
No organic chemistry, biochemistry, or environmental chemistry	Organic chemistry, biochemistry, and environmental chemistry concepts covered in SL and HL
Consideration of phase diagrams, colligative properties, and Nernst equation	No consideration of phase diagrams, colligative properties, and Nernst equation
Minimum of 90 minutes per week recommended (not required), preferably in one session, to be spent engaged in laboratory work	Laboratory work required, making up 25% of teaching time; required Group 4 project (student-designed research investigation) makes up 10 hours of work. (The project's intention is that students analyze a topic or problem that can be investigated in each of the science disciplines offered by a school. The topic can be set in a local, national, or international context.)

SOURCE: Adapted from CEEB (2001a) and IBO (2001).

MATERIALS USED

A list of suggested textbooks is given in the *Advanced Placement Program Course Description: Chemistry* (CEEB, 1999a, 2001a). These suggested textbooks are among those most frequently used in introductory college chemistry courses. In many cases, especially in classes taught by inexperienced teachers, the textbook forms the basis of the AP chemistry course. In an effort to finish the book, many of these teachers may try to cover all of the text before the May examination date. The broad scope of these textbooks contributes to an emphasis on breadth of coverage at the expense of depth of understanding.

Because of the unique structure of the IB chemistry courses, the IBO maintains that there are no suitable textbooks that can serve as the basis for its courses. Instead, the IBO publishes and disseminates a document, *Chemistry Bibliography*, which lists general resources. It is divided into Pre-IB, Core/General, Core and Higher Level, Organic, and General/Organic textbooks. It lists resources for each option and suggests sources for practical work (laboratories), comprehension exercises/review material, post-IB, and demonstrations, as well as periodicals and a list of data/useful sources of

information (including Web sites). Teachers are encouraged to select the materials that best align with the common core and optional topics that they teach in their classrooms.

LABORATORY WORK

The average length of a high school class per day (42–58 minutes) poses a challenge with regard to the amount of material that can be presented and actually learned in advanced chemistry courses. Increasingly, schools have adopted block-scheduling options, allowing up to 90 minutes for class and laboratory sessions. Even with this additional time allotted to laboratory work, however, time can be a true barrier to meaningful laboratory activities, especially those that are investigative in nature rather than applying a confirmatory or validation approach to preexisting knowledge. Investigative laboratories can occupy large amounts of time, and the amount of time recommended by the College Board for more traditional laboratories may not be sufficient for these new paradigms and approaches. In addition, college and university chemistry courses typically have affiliated weekly 3- or 4-hour laboratory periods during which students can perform actual investigative experimentation that includes multiple trials, replications, and the examination and evaluation of varying methodologies. This raises questions about the alignment of students' AP laboratory experiences with those available to college students. The panel notes that increasing numbers of high schools are working to find innovative ways of extending opportunities for laboratory work, which the panel commends.¹⁸ The panel applauds the College Board's clearly expressed guidelines that AP chemistry courses need to have a weekly extended laboratory period.¹⁹ The College Board explicitly states that "*it is not possible to complete high-quality AP laboratory work within standard 45-to-50 minute periods*" (CEEB, 1999a, p. 35) (emphasis in original). The College Board recommends that a minimum of 90 minutes weekly be spent in laboratory instruction, preferably in one session. It would

¹⁸One reviewer of this report pointed out that a serious curricular problem is the increasing tendency for high schools to condense the AP course into one semester through the use of block scheduling. The panel contends that, to benefit most from the AP chemistry experience, students should take the course throughout an entire academic year. The panel views as counterproductive any attempt to complete the AP chemistry course in one semester. The panel contends that the material in a college-level chemistry course contains too many concepts to be mastered in this truncated period of time. A one-semester course also does not allow the practice time needed to fully grasp what are for most high school students sophisticated chemical and affiliated mathematical concepts.

¹⁹The College Board recommends but does not require that students participate in particular types of laboratory experiences.

be desirable to know what percentage of AP chemistry courses follow this recommendation.

High school chemistry laboratory experiences are of mixed quality as a result of variations in resources, time available for faculty to set up and maintain laboratory experiments, and the academic background of faculty who teach these courses. When done at all, laboratory work can tend more toward verification than problem-solving investigations. The chemistry panel believes it would be desirable to avoid the former exercises and instead emphasize inquiry-based experiments. Moreover, teachers and administrators would likely pay more attention and commit more time and resources to enhancing laboratory experiences if the culminating AP examination stressed and tested for the knowledge, skills, and techniques that are gained primarily, if not exclusively, through laboratory experiences.

The IB examination has more laboratory-based questions than its AP counterpart, but still relatively few. Unlike the AP program, however, IB includes a student's laboratory grade as a component of the final course grade. It should be noted that the IB program also requires students to prepare portfolios in which they demonstrate their ability to plan, design, and analyze scientific experiments. While these components of the portfolio may draw on experiences in addition to those from the laboratory, they contribute to the student's development of skills and understanding of scientific procedures provided by laboratory experiences. Finally, the IB program requires teachers to submit a detailed description of the Practical Scheme of Work (PSOW) completed by all students, as well as examples of work from each individual student. Guidelines for assessing laboratory work are detailed extensively in the IB Diploma Programme Guides.

The chemistry panel notes that in 1999 the AP examination introduced a required laboratory-based question in the free-response section (CEEB, 1999b). Should this question continue to be structured so as to assess students' understanding of laboratory techniques and data acquisition, this will be a positive step. The panel believes, however, that *all* of the subparts of the laboratory-based question should be directed to laboratory techniques, experimental design, and data acquisition and interpretation, rather than to theoretical constructs. Because the AP examination contains only one question about laboratory work, including experimental techniques, an AP student could score well enough on the other parts of the examination to earn college credit without ever having undertaken any of the suggested laboratory work.

The chemistry panel heard anecdotal accounts of AP chemistry teachers who omit or defer laboratory activities to review previous AP examinations. In such circumstances, laboratory work, if done at all, is crammed into the course after students have taken the AP examination. This deplorable practice appears to result from teachers recognizing and taking advantage of the

lack of laboratory questions on the examination. Such practices disregard the validity of laboratory work as a means of introducing, reinforcing, consolidating, and amplifying chemistry principles. The fact that a number of colleges and universities require proof of sufficient chemistry laboratory work before granting credit or placement out of the general chemistry course indicates that laboratory work is a weak link in the AP course because of the variability in the way the laboratory component is administered.

In contrast, the IBO requires that teachers assess student work, with samples being sent to the IBO for moderation. The IBO allows only 2–3 hours of work to be carried out after the deadline, which prevents teachers from leaving laboratory work until the end of the course. Further, the IBO provides detailed guidelines and rubrics for assessing practical work (IBO, 2001, pp. 15–32).

CURRICULUM AND METHODS OF INSTRUCTION

Given the broad scope of the AP and IB chemistry curricula, it can logically be inferred that large components of AP and IB chemistry courses may be taught by the traditional method of “filling the open vessel”—lecture, note taking, and assessment by recall. These practices are in stark contrast with the constructivist model of learning recommended by the *National Science Education Standards (NSES)* (National Research Council [NRC], 1996) and other recent reports (NRC, 2000b). Those studies clearly demonstrate that students learn more deeply when they develop an understanding of the material while undertaking inquiry-based, problem-centered activities. Based on the materials examined, the chemistry panel agrees that neither AP nor IB appears to emphasize such approaches to learning. Rather, the breadth of topics included in AP and IB course outlines and syllabi indicates that far too much emphasis is being placed on covering a large body of information deemed necessary for success on the examination.²⁰

The kinds and levels of questions that appear on both the AP and IB examinations reinforce the emphasis on broad but shallow coverage of topics. Thus, an overarching, largely unintended, but nevertheless real and perverse effect is that the exam-driven nature of both programs may cause the development of intellectual curiosity in students to fall victim to the pace of the courses—all in the name of “rigor.”

The chemistry panel also is concerned that the current system of basing the AP chemistry course on typical or average general chemistry courses

²⁰The panel notes that the IB’s internal assessment component is not taught in a traditional manner and is consistent with the recommendations and emphases for teaching and learning in the *NSES*.

(using information gathered through surveys of chemistry departments at colleges and universities that receive the greatest number of AP candidates [see, e.g., CEEB, 1999a]) precludes incorporating emerging best practices that are beginning to appear in some college-level chemistry courses. Further, because AP courses are based on average college general chemistry courses, these changes will not be reflected in AP courses until changes in college-level chemistry become widespread.

A far better model would be to base AP chemistry courses on best practices in the teaching of college chemistry, even if the resulting course were less similar to typical college courses than is now the case. The panel notes that neither the AP nor IB chemistry course as yet accurately reflects recent efforts to restructure and change teaching and learning in general chemistry at the college/university level. Among such changes are emphases on “less is more” in terms of course coverage, a wider variety of assessment techniques, small-group and inquiry-based learning, and inquiry-based laboratories (NRC, 1999). *The AP and IB chemistry courses also do not yet recognize the increasingly interdisciplinary nature of modern chemistry; its incorporation of highly important related fields, such as materials science and biochemistry; and the opportunities presented by such fields to teach related chemical concepts in a contextual manner.* It is important to note that the College Board established the Commission on the Future of the Advanced Placement Program (CFAPP) to make recommendations regarding the future of the AP program. The commission recommends in its recent report, *Access to Excellence: A Report of the Commission on the Future of the Advanced Placement Program* (CFAPP, 2001), that leaders in the subject disciplines, pedagogy, and research be engaged to ensure that current reforms and best practices are reflected in AP examinations.

QUALITY CONTROL

To be successful, an AP chemistry course should be initiated only after a school's administrators and faculty have carefully considered the valid reasons for offering such a course. Such consideration should be followed by a thorough analysis of the resources—personnel, facilities, and supplies—available at the school to support the course. While these considerations would appear obvious, high schools are not bound by them (CEEB, 1999a). A school can offer an AP chemistry course by administrative fiat, even when the personnel, facilities, and supplies available for the purpose are not up to the expectations of the College Board, as noted in the Acorn Book for chemistry. It is not unreasonable to expect the College Board to exercise some control over where AP chemistry courses are offered and who teaches them. It is therefore encouraging to note that *Access to Excellence*, completed after the chemistry panel had conducted its deliberations, contains the recom-

mendation to develop and implement standards for AP programs in schools and school systems, for AP teachers, and for professional development workshops and institutes for AP teachers. *Access to Excellence* also recommends that the College Board take a more proactive approach to leading educational reform by changing the emphasis of the AP program from one of replicating typical college courses to one of emulating best practices in the discipline. The report further recommends that leaders in the subject disciplines, pedagogy, and research be engaged to ensure that current reforms are reflected in AP examinations. The chemistry panel endorses these recommendations fully and is pleased to learn that the College Board is willing to serve as a forum and vehicle for stimulating educational reform.

The College Board's expectations for teacher qualifications are explicit: "if the objectives of a college-level general chemistry course are to be achieved, the teaching should be done by a teacher who has completed an undergraduate major program in chemistry including at least a year's work in physical chemistry" (CEEB, 1999a, p. 3). However, the College Board does not have a means of verifying that AP chemistry teachers have these minimum qualifications or certifying them as competent to teach AP-level courses and associated laboratory activities. This lack of oversight and control is in addition to the College Board's lack of a mechanism for determining whether a school has adequate facilities and supplies before allowing it to offer an AP chemistry course. Nor does a mechanism exist for making such a determination once an AP chemistry course is being taught or for preventing a school from continuing to offer the course if the school is found lacking until the shortcomings are addressed. The CFAPP (2001) does not recommend certification of schools or teachers, but recommends instead that the College Board develop and disseminate AP quality standards for teachers, schools, and school systems. The commission also recommends that the College Board undertake a rigorous and systematic program of research to validate that (1) AP examinations actually test what is covered in the corresponding college courses and (2) students who earn specific scores on AP examinations have indeed mastered subject matter at a level equivalent to that of students who take these courses in college.

In contrast, before a school is authorized to offer an IB chemistry course, the school must be authorized to offer the complete IB Diploma Programme. One factor in this authorization process is an evaluation of the qualifications of the people who will teach the individual IB courses. In the sciences, a school that is seeking authorization also must demonstrate a plan for an acceptable set of laboratory activities relative to its resources. Sample laboratory reports must be sent periodically to IBO headquarters for critical review (IBO, 1999). It should be noted, however, that IB program administrators provide minimal oversight to ensure that the program standards are maintained over time. However, assistant examiners who encounter schools ex-

periencing difficulties with the program try to inform the IBO of these situations. Further, in the sciences, ongoing evaluation of a school's program continues through the IBO's moderation of sample laboratory reports and teachers' PSOWs that are submitted annually. Feedback is provided to the schools and teachers to promote improvements.

Students cannot take the IB examination without having taken the course. In contrast, students can register to take the AP chemistry exam without ever having taken an AP course, although this is not typically the case. The obverse is also true: students who take an AP chemistry course are not required by the College Board to take the examination. The College Board tracks only those students who take the examination. Although it does not have precise data about the number of students enrolled in AP courses, the College Board estimates that approximately 63 percent of students who are taking a course designated as AP sit for the AP examination in that subject. This, however, is the estimate for AP courses *in toto*. Currently, data are not available from the College Board for individual subject areas, such as chemistry. Consequently, the percentage of those students taking an AP chemistry course who do not take the AP exam is not known.²¹ Accordingly, the panel believes that statements by the College Board about the quality of AP chemistry courses are suspect because they fail to account for the many AP courses nationwide in which large numbers of students may not take the examination. In addition, the AP examination results are not available until after the end of the academic year. Thus the final grade received in an AP chemistry course is not specifically linked with the student's performance on the AP examination. Furthermore, since AP examination scores are not available until students have completed the course, there can be no grade-related consequence in the course from not taking the AP examination or, if taken, from doing poorly.

The panel also notes that commercial vendors, some of them linked with a university (e.g., the Michigan State University program), now offer AP courses on the Internet to individual students. This new development allows students who pay the necessary fees to take an AP course independently of whether their school offers an AP course in the same subject. Internet-based courses are self-pacing. The pace and calendar are established by the examination date, should the student choose to take the examination. In courses with a laboratory component, such as chemistry, arrangements for laboratory work may be irregular. In some situations, the laboratory work is done at a nearby campus or high school during weekends or other periods when several laboratory experiments are conducted in an intense burst of work. In these circumstances, the timing of laboratory activities may not correlate

²¹The College Board recently began to gather such data from school AP coordinators.

well with the chemical principles being studied at that point. Simulations of laboratory experiments are also used, although current simulations offer no opportunity for students to gain facility and dexterity in the proper manipulation and use of laboratory equipment.

COURSE CONTENT AND EXAMINATIONS

The 75 multiple-choice questions on the AP chemistry examination (Section I) match closely the objectives stated in the Acorn Book for an AP chemistry course. Despite the rather long list of chemical topics and concepts to be included in the AP curriculum, Section II of the examination asks questions evaluating a more limited set of topics. In addition, the panel finds that the topics tested in both parts of the examination are rather predictable from year to year and formulaic in the way in which the concepts are queried,²² especially in Section II. Certain topics and the style of questions addressing them change little from year to year. One example is the standard question in Section II, Part B of the AP examination that is related to reactions and writing of their affiliated chemical equations. (Although this question could perhaps be described as a laboratory-based question, the panel believes that students can answer the question correctly by sheer rote memory without ever having done any of the laboratory work.) Given this type of predictability in the examination's coverage from year to year, together with teachers who are very familiar with the general content and structure of the test, students may be able to earn high scores on the examination without actually having mastered all the material. This is especially true when students are given a choice of which questions to answer in Section II.

Some of the IB questions are identical in content to the chemical systems described and covered in the syllabus, thus requiring only rote learning with little mastery or understanding. In fact, there is an injunction from the IBO to IB instructors against using chemical systems other than those on the examination when teaching a given topic.

AP examinations ask less than IB exams about the application of concepts, especially with respect to new contexts or chemical systems. There is heavy emphasis on algorithmic solutions, rather than the extension or application of concepts to new, unfamiliar but equivalent situations. Few of the questions test students' abilities to predict or explain observations. For example, students could successfully write and balance sets of chemical equations with little understanding of the principles of chemical reactivity involved and no knowledge of the associated phenomena. The tests assess

²²In large part, this level of predictability is based on the Educational Testing Service's emphasis on and close monitoring of exams to maximize their reliability from year to year.

primarily the acquisition of information, as opposed to analyzing students' understanding, application, and extension of concepts. The examinations thus do little to encourage inquiry-based learning.

The chemistry panel drafted samples that demonstrate how questions taken from the 1999 AP chemistry examination could be modified to accomplish several objectives: requiring critical thinking, combining qualitative and quantitative aspects of a chemical system within a given question, and applying concepts to chemical systems and situations not previously encountered. The suggested modified questions are presented in Appendix D. By using the approaches illustrated by these types of questions, the AP and IB programs would encourage teachers to teach in less algorithmic ways and students to learn in a different, more inquiry-based manner as recommended by the *NSES*.

The AP examinations have yet to address the shift in increasing numbers of introductory college/university chemistry courses toward including applications in biochemistry, materials science, or environmental chemistry. The IB program and examinations include some applications in biochemistry and environmental chemistry but still lack attention to materials science.

4

Teachers and Teaching

TEACHER PREPARATION AND PROGRAM QUALITY

It should be self-evident that to teach a subject well requires at least a solid academic background in and working knowledge of the subject matter being taught. In addition to knowing the subject matter, however, a skilled chemistry teacher has the pedagogical insights necessary to present chemical concepts most effectively to different students. Clearly, no less should be expected of those who teach Advanced Placement (AP) or International Baccalaureate (IB) chemistry. To provide a chemistry course in line with the criteria for an advanced study course in chemistry at the high school level noted in Chapter 2, those who teach such a course must be adequately prepared. *The chemistry panel takes this minimum level of preparation to mean a B.S. or B.A. degree in chemistry that includes a full year of physical chemistry.* This view of the panel is congruent with that of the College Board, which recommends that an AP chemistry teacher have completed an undergraduate major in chemistry, including a year's work in physical chemistry (College Entrance Examination Board, 1999a, 2001a). This expected level of preparation also is consistent with recommendations from the National Science Teachers Association (1998) and the finding of the National Commission on Mathematics and Science Teaching for the 21st Century that “the most consistent and powerful predictors of higher student achievement in mathematics and science are (a) full certification of the teacher and (b) a college major in the field being taught” (2000, p. 18). *The members of the chemistry panel would extend this recommendation to state that high school teachers who offer advanced courses in chemistry should also have earned an M.A. or M.S. degree in chemistry, although the panel recognizes that realizing this goal would be difficult given the current and expected future shortages of science teachers.*

The reality is, however, that there is enormous variability in the subject matter preparation and backgrounds of chemistry teachers in the United States. There are well-prepared and experienced teachers who teach AP chemistry at the level expected by the College Board. Yet despite growing demands for AP and IB chemistry courses in more schools and in more states, the pool of teachers actually qualified to teach the courses is small (Blank, 1992). As the number of schools desiring to offer these courses increases while the pool of qualified teachers fails to keep pace, a point will be reached at which the ability of many schools to offer quality AP or IB chemistry courses will be seriously compromised. If such is the case, the very credibility of many AP and IB chemistry courses may be called into question.

Within the past decade, a significant effort has been made nationally to change the way in which chemistry and other science teachers are certified (National Research Council [NRC], 1997). A shift in an increasing number of states has led to the requirement that teachers have either a college major or a defined number of designated academic credits in the subject matter of the field to be taught (National Science Board, 1998). Currently, 29 states require that high school teachers have a degree in the subject matter they teach, rather than an education degree. As of 1993, 63 percent of all grade 9–12 teachers of science had a major in science, while nearly three-quarters (72 percent) had a major in science or science education. Although encouraging, these data fail to take into account the fact that two-thirds of all states permit a “broad-field” secondary science certification, which certifies teachers to teach across a range of science subjects (chemistry, physics, biology, and earth or space science). In at least eight states, the broad-field certification encompasses the same number of semester credit hours as the states’ single-science certification (Blank, 1992). Of the nearly 65 percent of those with a major in science who are teaching science in grades 9–12, almost one-third are doing so under a broad-field secondary science certification. More than half of teachers teaching physical science classes (chemistry, physics, earth science, or space science) do not have an academic major or minor in any one of the physical sciences (NRC, 2000a, pp. 50–51). Additionally, data from the Council of Chief State School Officers ([CCSSO], 1997) indicate that approximately half (53 percent) of those teaching chemistry do so as their primary teaching assignment.

These data raise serious questions concerning the adequacy of academic background preparation for many of those who teach even the first-year course in chemistry, let alone advanced courses in the subject. Additional research is required to document the relationship between teaching effectiveness in introductory courses and student performance in advanced courses. However, it appears logical that students in first-year courses who are taught by underprepared chemistry teachers are more likely to lack the founda-

tional concepts and skills needed to complete advanced study work successfully, as compared with students whose teachers have mastered content knowledge and effective pedagogical approaches to teaching chemistry. The effect is compounded if the same teachers who teach the first-year courses inadequately are assigned to teach the advanced study chemistry course as well.

TEACHER SELECTION, DEVELOPMENT, AND SUPPORT

Many high schools have only one chemistry teacher. As noted, this individual also is likely to teach other science courses (CCSSO, 1997). For an AP chemistry teacher in this situation, the AP assignment increases the number of required course preparations as well as the number of different laboratory preparations, along with their attendant difficulties. If this teacher also teaches nonchemistry courses (biology or physics, for example), he or she must remain informed about developments in those subject areas as well. Perforce, this reduces the amount of time the teacher has to remain abreast of developments in chemistry and thus adequately prepared for the AP chemistry course.

As noted earlier, the chemistry panel believes strongly that an AP or IB chemistry course cannot be taught appropriately by an instructor whose background in the content of the subject is insufficient. For example, it is the panel's position that a B.S. in science education does not adequately prepare an individual to accept an AP or IB chemistry assignment without completing further coursework in chemistry. This view, too, is consonant with the recommendation of the College Board that a teacher of AP chemistry have an undergraduate major in chemistry.

Data are unavailable about the exact qualifications and academic preparation of current AP or IB chemistry teachers. The way in which those who teach AP or IB chemistry are selected or assigned to do so also appears to vary considerably among schools. First-year teachers, veteran teachers, and those whose experience levels fall anywhere between these extremes may be given this assignment. In many school districts, seniority appears to play a significant role in the selection—even when the individual selected through seniority is not as well prepared as less senior colleagues.

PROFESSIONAL DEVELOPMENT

The College Board offers a variety of professional development opportunities to support AP chemistry teachers. Such support includes summer institutes, workshops, and seminars. New AP chemistry teachers are invited

to attend 1- or 2-week summer institutes to learn the rudiments of teaching an AP course, its laboratory component, and the College Board's expectations for the course. There are also 1-day seminars held regionally to update AP chemistry teachers on teaching developments and changes in the AP courses or examinations. In addition, teachers from schools that participate in AP courses are invited to videoconferences where they can learn from those who develop AP examinations and review AP courses. And an online discussion group is available for AP chemistry teachers to share syllabi, compare teaching strategies, and discuss substantive issues related to the content of the course or chemistry in general. Frequently, college instructors participate in these discussions, providing a forum for discussions between high school and college faculty around the teaching of chemistry. Participation in the regional workshops and online discussion groups is free.

AP summer institutes are not free. The College Board supports some of them, and schools sometimes bear the costs for their teachers to attend, but not always. Absent such support, the length of the institutes (1 or 2 weeks) and their associated costs (travel, registration, meals, housing), if not covered by a school, district, or state, are a disincentive for teachers to attend, particularly when such attendance is voluntary and outside of paid contract hours. The structure and format of these institutes vary. Most offer sessions on pedagogy and an orientation to the AP chemistry course, its laboratory, and the AP examination. However, the institutes do not address the major shortcoming of some AP teachers noted above—an inadequate background and the lack of a deep understanding of the chemistry principles necessary to teach the AP course material successfully. As noted above, a deep conceptual understanding of the content and unifying concepts of chemistry is a critical requirement for effective teaching in the discipline.

The panel encourages the College Board to provide a substantial and sustaining level of guidance and oversight for the preparation of teachers, student learning, and support by school systems so that high school AP chemistry courses can be of the high quality espoused by the College Board. Such efforts might include expanded and enhanced support for teachers, the establishment of creative partnerships for teacher professional development, and the development of comprehensive services for schools and school systems to help them design and implement successful AP programs. Recommendations contained in *Access to Excellence* support the panel's views in this regard (Commission on the Future of the Advanced Placement Program, 2001, pp. 9–11):

- Provide unconditional support for preparing teachers, schools, and school systems to offer high-quality AP programs—teachers' needs are paramount (Recommendation 2).

- Expand and enhance direct support for teachers (Recommendation 2a).
- Develop creative partnerships and tools to enhance teacher professional development (Recommendation 2b).
- Promote the development of online support for teachers (Recommendation 2c).
- Develop comprehensive services to help administrators, principals, and counselors design and implement successful AP programs (Recommendation 2d).

The IB program also holds professional development workshops for teachers. All new IB teachers are required to attend one of these workshops, preferably before they begin teaching. Most IB experimental science teachers agree that these workshops are critical for new teachers because of the complexity of the Group 4 subject syllabi and the requirements for the Practical Scheme of Work and the Internal Assessment (IA). IB teacher workshops for the experimental sciences frequently focus on designing laboratory experiences that will enable students to meet the specific IA criteria. Additionally, these workshops help new teachers develop strategies for managing the record-keeping activities that are demanded by the International Baccalaureate Organisation. International Baccalaureate of North America is responsible for conducting these workshops, but they most often are designed and led by experienced IB teachers. It is important to note that these workshops often are held in remote locales, making travel to attend them expensive and difficult and thereby reducing the number of attendees.

5

Outcomes of AP and IB Chemistry Courses

USE OF AP AND IB CHEMISTRY EXAMINATION SCORES BY COLLEGES AND UNIVERSITIES

Colleges and universities vary significantly in the ways in which they handle credit and placement decisions based on Advanced Placement (AP) and International Baccalaureate (IB) chemistry examination scores (College Entrance Examination Board [CEEB], 1994). The options include the following:

- No advanced placement or college credit granted
- Advanced placement granted, but no credit given
- College credit given, but no advanced placement
- College credit and advanced placement given

Some states legislate the awarding of particular levels of college or university credit to students with specified minimum AP scores. Statewide higher education systems in some states have well-articulated, shared policies among their institutions regarding credit and advanced placement for students meeting system-wide AP score standards; systems in other states leave the matter to the discretion of the institution or individual departments. Examples of the credit and advanced placement practices listed above are cited in the *College and University Guide to the Advanced Placement Program* booklet from the College Entrance Examination Board (1994).

DEGREE TO WHICH AP AND IB CHEMISTRY PROGRAMS REFLECT EMERGING KNOWLEDGE OR APPROACHES IN CHEMISTRY

The consensus opinion of the chemistry panel is that neither the IB nor AP examination reflects several significant recent developments in the focus

of chemistry research and in the teaching of chemistry at the college/university level. Practice in the field of chemical research has shifted to incorporate work at the intersection of chemistry with disciplines that in the past have been viewed as different from mainstream chemistry—biology, engineering, materials science, and environmental science. Major research programs now exist in materials science, bioinorganic and biopolymer chemistry, atmospheric chemistry, and nanotechnologies. To prepare students to understand such interdisciplinary research, increasing numbers of college and university general chemistry textbooks and laboratory curricula are incorporating organic and biochemical moieties to teach general chemistry principles, thus breaking down the artificial barriers among subdisciplines and using these developments as opportunities to teach related chemical principles in a more contextual manner (see, e.g., *ChemConnections* modules;²³ *Chemistry: Structure and Dynamics* [Bodner, Rickard, and Spencer, 1999]; *The Chemical World: Concepts and Applications*, 2nd edition, [Moore, Stanitski, Wood, Kotz, and Joest, 1998]; Landis and Peace, [1998]); and the *Discovery Chemistry* curriculum from the College of the Holy Cross²⁴). These textbooks and laboratory experiments also cover exciting new developments in materials science, such as those developed at the University of Wisconsin, Madison.²⁵ Because they offer a different focus and context for introductory chemistry courses, the authors of these texts have made the difficult decisions about what subject matter to deemphasize so that faculty will have sufficient time to teach the concepts these texts emphasize.

The AP topic outline and the associated examination do not yet reflect such changes. Although the College Board introduced aspects of organic chemistry into the AP chemistry course in 1997, no questions about organic chemistry or biochemistry have yet appeared on the national examination. In contrast, the IB program does include some organic chemistry, biochemistry, and environmental chemistry, in part because it reflects a broader, international curricular base whereby students learn chemistry through a more holistic, spiral approach. Questions that are related to chemical principles of materials science are not part of either the IB or AP examinations.

The chemistry panel believes that to be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment incorporated in the *National Science Education Standards (NSES)* (NRC, 1996). Current practices in the way AP and IB chemistry programs assess student learning on the written final examinations do not appear to be responsive to the changes in emphasis suggested by the *NSES* for assessment, teaching, professional development, or content. The AP and IB

²³<http://mc2.cchem.berkeley.edu> [4/23/02].

²⁴<http://www.holycross.edu/departments/chemistry/discovery/index.html> [4/23/02].

²⁵See <http://mrsec.wisc.edu> [4/23/02].

examinations continue to assess primarily the acquisition and retention of information as distinct from understanding, applications, and extensions of concepts. The exams offer little reinforcement of inquiry-based learning in these examinations. As noted above, the IB program does meet many of the *NSES* criteria through its Internal Assessment protocol (e.g., portfolio assessment, use of rubrics, data analysis questions). The chemistry panel urges AP and IB staff and teachers to compare their current practices in instruction and testing against the changing emphases articulated in the *NSES* and the related recommendations of the American Chemical Society in *Chemistry in the National Science Education Standards* (1997) (e.g., emphasis on unifying concepts; use of inquiry-based teaching; cooperative and collaborative learning strategies; and incorporation of organic, environmental, and biochemistry topics). The AP program is silent with respect to recommending or supporting any particular teaching methodology. Its approach is outcome driven, with success being measured by examination scores, which in turn are content rather than concept driven. The chemistry panel is disappointed that AP, as the predominant national-level advanced study program in the United States, has apparently not considered as part of its responsibilities the promotion of approaches and innovations in teaching and learning that are more aligned with recommendations in the *NSES*.

At the same time, however, the College Board is not likely to be successful in making such changes if it does so unilaterally. The College Board will require overt and explicit support and encouragement for such reforms from professional societies, from college and university faculty who teach introductory chemistry courses, and from college admission offices that are prepared to accept students who take these kinds of revised courses.

SUCCESS IN CHEMISTRY BEYOND THE INTRODUCTORY LEVEL

Given the variability of AP and IB courses as implemented in different high schools, as well as the variability among college chemistry courses at different institutions, the success of individual AP students in higher-level college courses is also likely to vary considerably. During the past 25 years, several studies (all conducted under the auspices of the College Board)²⁶ have attempted to examine whether students who take AP courses in high school are successful in college and whether they are as well prepared as their non-AP counterparts for second- and third-level college courses in the

²⁶These studies are published as in-house documents only. They have not been peer reviewed and do not appear in any scholarly publications, such as professional journals. This issue also is addressed in Chapter 10 of the report of the parent committee.

discipline. While the data appear to indicate that AP students on average are well prepared, the methodology used in these studies makes it difficult to ascertain whether student success can be attributed to the AP program or to other factors, such as the colleges they attend, the classes they take, or their own academic backgrounds and abilities (see Appendix E). The panel therefore takes a cautious approach to accepting the findings of these studies.

6

Summary and Recommendations

The Advanced Placement (AP) and International Baccalaureate (IB) chemistry courses now being offered are taught effectively according to the expectations of the College Board and the International Baccalaureate Organisation (IBO) in some, but by no means all, schools. The content of the courses is bound inextricably to the nature and corpus of questions on the affiliated AP and IB examinations, which the chemistry panel finds to be flawed, as described in previous chapters. It should be noted that there is a growing tendency for IB chemistry classes in the United States to be offered as 1-year courses, in order to conform to U.S. high school timetables. This practice contrasts with that of other countries, where virtually all IB chemistry classes are taught over 2 years. Thus, in many IB chemistry courses offered in the United States, too much information may be crammed into the course for the time available. The following sections summarize the panel's findings and recommendations regarding the AP and IB chemistry courses and examinations and the qualifications and professional development of those who teach the courses.

FINDINGS AND RECOMMENDATIONS REGARDING THE AP AND IB COURSES AND EXAMINATIONS

1. The chemistry panelists agree that advanced study options in high school chemistry should not necessarily be tied to the potential for earning college/university credit. The chemistry panel views these as two separate issues:

(a) The panel members are unanimous in agreeing that advanced study of chemistry at the high school level should provide students with a coherent, rigorous course that promotes further scientific lit-

eracy and prepares students to become part of a highly technological workforce, regardless of whether they continue studying chemistry at the tertiary level.

(b) An advanced chemistry course that meets criterion (a) should be organized and delivered such that it would be equivalent to the two-course college/university general chemistry sequence and such that college credit could be sought based on passing the placement examination that is administered by college or university departments of chemistry. That is to say, advanced study in chemistry need not be based on AP or IB. Indeed, many of the nation's top high schools for mathematics and science offer advanced courses that are neither AP nor IB based. Other legitimate alternatives should be explored.

2. Institutions awarding AP examination-based course credit or advanced placement should consider doing so only for a grade of 4 or 5, not for a grade of 3. The College Board is currently conducting studies on the validity of a grade of 3 for the awarding of college credit, and the panel applauds this effort. However, until that study is complete, it remains unclear whether students who have earned a score of 3 have achieved sufficient understanding of the subject matter at a level comparable to college courses to merit credit and placement out of the introductory course.

3. The chemistry panel recommends that to be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment contained in the *National Science Education Standards* (National Research Council [NRC], 1996).

FINDINGS AND RECOMMENDATIONS REGARDING THOSE WHO TEACH AP AND IB CHEMISTRY COURSES

1. The chemistry panel recommends that to be a qualified AP or IB teacher the teacher must have a B.S. or B.A. degree in chemistry (which includes a two-semester physical chemistry course sequence with laboratories) and preferably an M.A. or M.S. degree in chemistry. The chemistry panel does not view a B.S. in science education as being adequate preparation for these teachers, nor does the College Board.

2. A qualified advanced study chemistry instructor should have experience with effective current and emerging approaches to chemistry teaching and assessment in the subject and their applications to the AP and IB chemistry courses.

3. The qualified AP or IB chemistry teacher should have a working familiarity with teaching technologies (e.g., Web, electronic media, laboratory instrumentation) and their appropriate uses.

4. There should be required periodic, funded professional development opportunities, including content instruction, research participation, and pedagogy workshops, for teachers of advanced courses in chemistry. This recommendation is consonant with the Glenn Commission's description of what constitutes professional development: "a planned, collaborative, educational process of continuous improvement for teachers that helps them to do five things: (1) deepen their knowledge of the subject(s) they are teaching; (2) sharpen their teaching skills in the classroom; (3) keep up with developments in their fields, and in education generally; (4) generate and contribute new knowledge to the profession; and (5) increase their ability to monitor students' work, so they can provide constructive feedback to students and appropriately redirect their own teaching" (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, p. 18).

5. Professional development opportunities, such as the experience of teaching courses or laboratories at colleges or universities and undertaking original research in industry, at government laboratories, or in collaboration with college faculty, would be particularly valuable for AP and IB chemistry teachers. High-school system personnel policies should encourage rather than inhibit such professional development activities during the academic year.

6. AP and IB chemistry teachers can profit from discussions with each other. School districts and schools should find ways to initiate and sustain such conversations and to share them with a wider audience. Communication about areas of common interest between chemistry faculties in high schools and those teaching general chemistry in institutions of higher education would be extremely helpful for both communities (see also the recommendations under Vision 4 in *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* [NRC, 1999]).

7. AP and IB chemistry teachers should be participating members of professional organizations such as the National Science Teachers Association and the American Chemical Society's Division of Chemical Education. Through such participation, teachers gain a sense of belonging to a community of professionals who are similarly inclined to excel in their teaching. They gain access to colleagues and resources that would have been largely inaccessible without membership.

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Appendix A

Charge to the Content Panels from the Parent Committee

Charge to the Parent Committee and Content Panels: The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines. Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the committee's charge and study questions.

The panels should focus on the following specific issues in advising the committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facilitate retrieval and application in new contexts (see, e.g., National Research Council [NRC], 2000b).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?

2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?

3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of coverage with in-depth study of important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?

4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?

5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?

6. To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:

- a) students' mastery of content knowledge;
- b) students' understanding and application of concepts; and
- c) students' ability to apply what they have learned to other courses and in other situations.

2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience, and independent investigation)?
2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The NRC's *National Science Education Standards* (NRC, 1996) and the National Council of Teachers of Mathematics' Standards (2000) propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?
2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?
3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix B

Biographical Sketches of Chemistry Content Panel Members

Conrad L. Stanitski (committee liaison and chair) is professor of chemistry and chair of the Chemistry Department at the University of Central Arkansas. His principal focus is inorganic chemistry and general chemistry for science and nonscience majors. He is currently chair of the American Chemical Society (ACS) Division of Chemical Education, was a member of the ACS Committee on Education, has directed numerous ACS teacher-training workshops, is a (National Science Foundation) NSF proposal reviewer, and has been an invited speaker and workshop leader in seven foreign countries. Dr. Stanitski has authored or coauthored several highly regarded textbooks in the field, including *Chemistry in Context: Applying Chemistry to Society*; *The Chemical World: Concepts and Applications*; *Chemical Principles*; *Chemistry in the Community*; and *Chemistry for Health-Related Sciences: Concepts and Applications*. He received his B.S. in science education from Bloomsburg State College, his M.A. in chemistry education from the University of Northern Iowa, and his Ph.D. in inorganic chemistry from the University of Connecticut.

Arthur B. Ellis is Meloche-Bascom Professor of Chemistry at the University of Wisconsin at Madison. In addition to receiving numerous teaching awards, including the NSF's Director's Award for Distinguished Teaching Scholars, Dr. Ellis is currently involved in the creation of innovative instructional materials that integrate materials science into the chemistry curriculum. His research on the electro-optical properties of semiconductor interfaces has led to the development of new classes of on-line chemical sensors. He is currently serving a 2-year appointment to the National Research Council's (NRC) Committee on Undergraduate Science Education. Dr. Ellis received his Ph.D. from the Massachusetts Institute of Technology in inorganic chemistry. In July 2002, he will join the NSF as director of the chemistry division.

Patricia A. Metz is an assistant professor of chemistry at the United States Naval Academy. She specializes in the teaching and learning of chemistry and conducts research on curriculum development, instructional design, conceptual understanding, and assessment. She is responsible for the development of original guided-inquiry biochemistry and general chemistry laboratory classes for both chemistry and nonchemistry majors. Dr. Metz has published several articles related to instructional methods and diagnostic techniques. She received her Ph.D. from Purdue University in chemistry education.

John C. Oliver is a science teacher and department chair at Lindbergh High School in Saint Louis, Missouri, where he has taught a range of biology and chemistry classes, including both AP and IB chemistry. His teaching efforts have been recognized by awards, such as the Woodrow Wilson National Fellowship and local and regional high school teaching awards from ACS. Mr. Oliver actively pursues a variety of enrichment coursework in such fields as physics, chemistry, laboratory techniques, and chemistry education and is a member of numerous professional organizations. He received his M.A.T. in science education from Webster College in Saint Louis and an A.B. in zoology from the University of Missouri at Columbia, with a minor in chemistry.

David Pysnik is a chemistry instructor at Sidney Central Schools in Sydney, New York. He teaches the New York Board of Regents Chemistry, which is similar in content to the AP program, but he does not teach AP chemistry. Mr. Pysnik focuses on teaching through a research-based approach and has worked as a research associate at Ithaca College for the last 20 summers. He has developed mobile laboratory programs and has won the Catalyst Award from the Chemical Manufacturers Association, the Tandy Technology Scholars Award, the ACS Northeast Regional Award in High School Chemistry Teaching, and the Presidential Award for Excellence in Science and Mathematics Teaching. Mr. Pysnik received his B.S. from Juniata College and his M.S. from Indiana University.

A. Truman Schwartz is DeWitt Wallace Professor of Chemistry at Macalester College, where he previously served as chair of the chemistry department and dean of faculty. His research interests include chemical education, the history of science, and the physical chemistry of macromolecules. Professor Schwartz has contributed to several national curriculum reform projects, including the first two editions of *Chemistry in Context: Applying Chemistry to Society* and *ChemConnections*. On temporary assignment, he served as deputy director of the Teacher Preparation and Enhancement Division of the NSF. He has been honored with numerous teaching awards at the college,

state, and national levels. Professor Schwartz received a B.A. from the University of South Dakota, M.A. at Oxford University as a Rhodes Scholar and a Ph.D. in physical chemistry from the Massachusetts Institute of Technology.

Glenda M. Torrence is a science resource teacher at Montgomery Blair High School in Maryland, where she is actively involved with curriculum development for new and pre-existing courses, interdisciplinary cooperation with the mathematics and technology departments, and the implementation of assessment methodologies for the chemistry department. She has taught chemistry courses at the University of Maryland at College Park and was nominated for the Presidential Teaching Award. Dr. Torrence received her Ph.D. in physical chemistry from the State University of New York at Buffalo.

Appendix C

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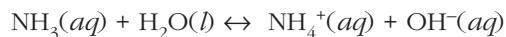
Appendix D

Suggested Modifications of Examination Questions

This appendix presents examples of the chemistry panel's suggested modifications to the questions on the Advanced Placement (AP) chemistry 1999 examination, Section II, to make the questions more contextual; to probe more carefully the depth of student understanding; to seek to assess higher-order thinking skills; to require the applications of chemistry principles in an enlarged or new context; and to enjoin students to link concepts to chemical systems and macroscale phenomena, not merely see chemistry principles as isolated facts. In particular cases below, the original question is given, followed by its suggested modification.

AP CHEMISTRY 1999, SECTION II, PART A, QUESTION 1

Original Question



In aqueous solution, ammonia reacts as represented above. In 0.0180 M $\text{NH}_3(aq)$ at 25°C, the hydroxide ion concentration $[\text{OH}^-]$ is 5.60×10^{-4} M. In answering the following, assume that temperature is constant at 25°C and that volumes are additive.

- Write the equilibrium-constant expression for the reaction represented above.
- Determine the pH of 0.0180 M $\text{NH}_3(aq)$.
- Determine the value of the base ionization constant, K_b , for $\text{NH}_3(aq)$.
- Determine the percent ionization of NH_3 in 0.0180 M $\text{NH}_3(aq)$.
- In an experiment, a 20.0 mL sample of 0.0180 M $\text{NH}_3(aq)$ was placed in a flask and titrated to the equivalence point and beyond using 0.0120 M $\text{HCl}(aq)$.

- (i) Determine the volume of 0.0120 M $\text{HCl}(aq)$ that was added to reach the equivalence point.
- (ii) Determine the pH of the solution in the flask after a total of 15.0 mL of 0.0120 M $\text{HCl}(aq)$ was added.
- (iii) Determine the pH of the solution in the flask after a total of 40.0 mL of 0.0120 M $\text{HCl}(aq)$ was added.

(SOURCE: CEEB, 1999b, p. 42)

Suggested Modification

The panel would suggest leaving much of question 1 alone, although it could stand to be condensed somewhat. As written, it tests the student's fundamental understanding of K_b , buffers, and titration stoichiometry. One or more of the following additional questions might be added:

Sketch a titration curve for part (e) using the information from (b), (c), and (d)

and/or

compare the base strength and give the rationale for strength based on the type of site and associated structure for one or two other more obscure bases, given their respective K_b 's.

AP CHEMISTRY 1999, SECTION II, PART A, QUESTION 2

Original Question

Answer the following questions regarding light and its interactions with molecules, atoms, and ions.

- (a) The longest wavelength of light with enough energy to break the Cl-Cl bond in $\text{Cl}_2(g)$ is 495 nm.
 - (i) Calculate the frequency, in s^{-1} , of the light.
 - (ii) Calculate the energy, in J, of a photon of the light.
 - (iii) Calculate the minimum energy, in kJ mol^{-1} , of the Cl-Cl bond.
- (b) A certain line in the spectrum of atomic hydrogen is associated with the electronic transition in the H atom from the sixth energy level ($n = 6$) to the second energy level ($n = 2$).

(i) Indicate whether the H atom emits energy or whether it absorbs energy during the transition. Justify your answer.

(ii) Calculate the wavelength, in nm, of the radiation associated with the spectral line.

(iii) Account for the observation that the amount of energy associated with the same electronic transition ($n = 6$ to $n = 2$) in the He^+ ion is greater than that associated with the corresponding transition in the H atom.

(SOURCE: CEEB, 1999b, p. 43)

(NOTE: On the exam, students were asked to answer *either* this question *or* the next question concerning reaction rates, but not both.)

Suggested Modification

A question containing some of the information assessed in the original version of Question 2 but considerably extended might look like this. This question now relates to a chlorofluorocarbon compound known as CFC-12 or Freon-12.

The Lewis structure of the CFC-12 molecule is: [structure would be given]

(a) Give the correct chemical name for this compound.

(b) Describe the geometrical shape of the compound and estimate the Cl-C-Cl angle.

(c) Identify the type of hybridization exhibited by the central carbon atom.

(d) The energy of the C-Cl bond is 327 kJ/mol bonds; the energy of the C-F bond is 485 kJ/mol bonds. Explain this difference.

or alternatively

(e) The energy of the C-Cl bond is 327 kJ/mol bonds. Would you predict the energy of the C-F bond to be higher or lower? Explain your answer.

(f) Calculate the frequency, in s^{-1} , of the radiation required to break a C-Cl bond.

(g) Calculate the wavelength (in nm) of the radiation required to break a C-Cl bond.

(h) Radiation of this wavelength falls within which region of the spectrum?

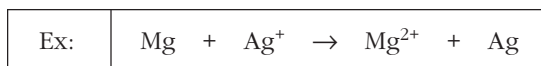
(i) What is the practical significance of the fact that radiation breaks C-Cl bonds in CFCs?

AP CHEMISTRY 1999, SECTION II, PART B, QUESTION 4

Original Question

Write the formulas to show the reactants and products for any FIVE of the laboratory situations described below. Answers to more than five choices will not be graded. In all cases a reaction occurs. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solution as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You need not balance the equations.

Example: A strip of magnesium is added to a solution of silver nitrate.



- (a) Calcium oxide powder is added to distilled water.
- (b) Solid ammonium nitrate is heated to temperatures above 300°C.
- (c) Liquid bromine is shaken with a 0.5 *M* sodium iodide solution.
- (d) Solid lead(II) carbonate is added to a 0.5 *M* sulfuric acid solution.
- (e) A mixture of powdered iron(III) oxide and powdered aluminum metal is heated strongly.
- (f) Methylamine gas is bubbled into distilled water.
- (g) Carbon dioxide gas is passed over hot, solid sodium oxide.
- (h) A 0.2 *M* barium nitrate solution is added to an alkaline 0.2 *M* potassium chromate solution.

(SOURCE: CEEB, 1999b, p. 45)

Suggested Modification

The panel would like to see the reaction/equation question tied more closely to phenomena and laboratory observation. In each of the cases below, the original version (a, b, c, etc.) and a suggested revision (a', b', c', etc.) are given. (The panel also is not convinced that requiring ionic equations is the most appropriate strategy.)

- (a) Calcium oxide powder is added to distilled water.
- (a') Calcium oxide powder is added to distilled water. Write the equation for the reaction and indicate whether the final solution will have a pH less than, equal to, or greater than 7.

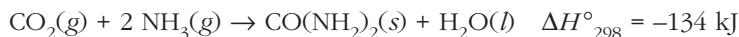
- (b) Solid ammonium nitrate is heated to temperatures above 300°C.
(b') The vapors from 6 *M* HCl and 6 *M* NH₃ combine to form a white cloud. Write the equation for the reaction.
- (c) Liquid bromine is shaken with a 0.5 *M* sodium iodide solution.
(c') 5.0 mL of a 0.5 *M* solution of sodium iodide is shaken with 5.0 mL of a water solution of bromine and 5.0 mL of hexane, C₆H₁₄. Describe what you would observe, and write an equation representing the reaction.
- (d) Solid lead(II) carbonate is added to a 0.5 *M* sulfuric acid solution.
(d') 0.5 *M* sulfuric acid is added to a small quantity of lead(II) carbonate in a test tube. Describe the first thing you would notice, and write an equation representing the reaction.
- (e) A mixture of powdered iron(III) oxide and powdered aluminum metal is heated strongly.
(e') A mixture of powdered iron(III) oxide and powdered aluminum metal is ignited with a burning piece of magnesium. Sparks, flames, and a pool of molten metal are formed. Write the equation for the reaction. What is the molten metal, and what does this imply about the reaction?

AP CHEMISTRY 1999, SECTION II, PART B, QUESTION 6

Original Question

Answer the following questions in term of thermodynamic principles and concepts of kinetic molecular theory.

- (a) Consider the reaction represented below, which is spontaneous at 298 K.



- (i) For the reaction, indicate whether the standard entropy change, ΔS°_{298} , is positive, or negative, or zero. Justify your answer.
(ii) Which factor, the change in enthalpy, ΔH°_{298} , or the change in entropy, ΔS°_{298} , provides the principal driving force for the reaction at 298 K? Explain.
(iii) For the reaction, how is the value of the standard free energy, ΔG° , affected by an increase in temperature? Explain.
- (b) Some reactions that are predicted by their sign of ΔG° to be spontaneous at room temperature do not proceed at a measurable rate at room temperature.

- (i) Account for this apparent contradiction.
- (ii) A suitable catalyst increases the rate of such a reaction. What effect does the catalyst have on ΔG° for the reaction? Explain.

(SOURCE: CEEB, 1999b, p. 47)

Suggested Modification

The panel suggests that Section II, Part B, Question 6 of the AP chemistry exam, which deals with thermodynamic principles and KMT concepts, could be directed to higher levels of thinking in part (a) by relating a simple system, such as an ice cube melting, to enthalpy, entropy, and free energy. The student could be asked to explain the process using the above terms and appropriate equations. Part (b) could be similar but related to something common, such as the possible oxidation of sucrose, which has a large negative free energy. The student could discuss why the sugar does not spontaneously combust on the kitchen table since the free energy is favorable. Included in the explanation would be descriptions of the differences between thermodynamic and kinetic stability.

AP CHEMISTRY 1999, SECTION II, PART B, QUESTION 7

Original Question

Answer the following questions, which refer to the 100 mL samples of aqueous solutions at 25°C in the stoppered flasks shown above (four partially full flasks are shown, each containing an equal volume of 0.10 *M* solutions of NaF, MgCl₂, C₂H₅OH, and CH₃COOH, respectively).

- (a) Which solution has the lowest electrical conductivity? Explain.
- (b) Which solution has the lowest freezing point? Explain.
- (c) Above which solution is the pressure of water vapor greatest? Explain.
- (d) Which solution has the highest pH? Explain.

(SOURCE: CEEB, 1999b, p. 48)

(NOTE: On the exam, students were asked to answer *either* this question *or* the next question concerning principles of chemical bonding and molecular structure, but not both.)

Suggested Modification

The panel suggests the following modified question:

Modification 1. Do not have all solutions be 0.10 *M*. Instead use 0.010 *M* NaF, 0.050 *M* MgCl₂, 0.10 *M* C₂H₅OH, and 0.20 *M* CH₃COOH. This change requires a student to think more critically about the nature of these solutions to answer the subsequent questions correctly. More discrimination is required to differentiate acetic acid from NaF and from MgCl₂ solution behavior.

Modification 2. If the stoppers were removed from the flasks, from which flask would the solute escape most readily? Explain the answer.


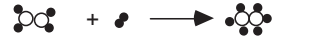

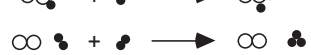

Modification 3. The contents of which flask(s) could be used as reactant(s) in an esterification reaction? Explain.

This would become a more challenging question if varying concentrations of the compounds in water were used. This change would make the question quantitative and more difficult. The quantitative nature of question 7 would make it less appropriate as a companion for question 8. These two questions should be of like nature and degree of difficulty. To avoid the quantitative aspect of concentration calculation, it would be appropriate to ask the student to identify the type of substance for each question and to write a dissociation, ionization, hydration equation (as necessary) for these substances in water and discuss their relative activity.

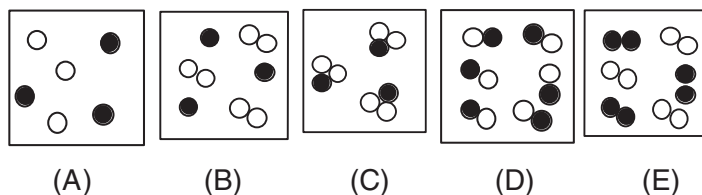
These three items are examples of particulate representations linked to symbolic representations or macroscopic phenomena. Such questions are not part of the AP or IB examinations.

1. Which particulate representation corresponds to the equation?

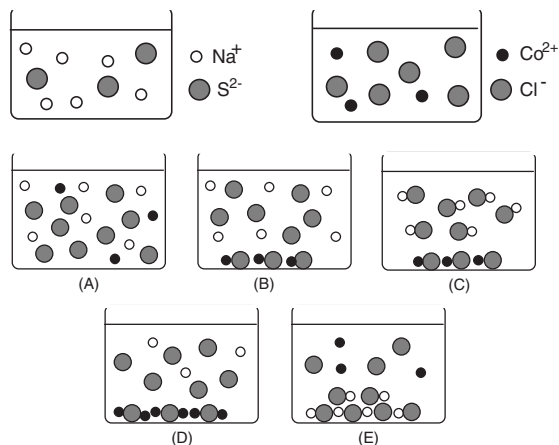


- (A) 
- (B) 
- (C) 
- (D) 
- (E) 

2. Which would best represent a mixture of the gases helium and chlorine?

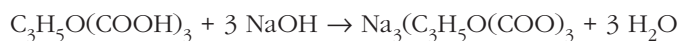


3. If the contents of these two beakers are poured into a third beaker, what will the resulting mixture look like?



This is an example of an error analysis-type item.

4. A student titrated 10.00 mL of fruit juice with 12.84 mL of $9.580 \times 10^{-2} M$ NaOH. Which step is NOT correct in this calculation of mass of citric acid in 1.00 mL of juice?



- (a) Moles NaOH = (12.84 mL) (9.580×10^{-2} mol/L).
- (b) Moles citric acid = (1.230 mol NaOH) (1 mol citric acid/3 mol NaOH).
- (c) Mass citric acid in sample = (0.4100 mol citric acid) (192.12 g/mol citric acid).
- (d) Mass citric acid in 1 mL fruit juice = (78.77 g citric acid)/(10.00 mL fruit juice).
- (e) All the steps are correct.

This is an example of a laboratory-related item.

5. Consider a laboratory exercise in which you prepare approximately 200 mL of a pH = 4.35 buffer. The chemicals available for your use are: 1M solutions of acetic acid, ammonium acetate, ammonium chloride, aqueous ammonia, hydrochloric acid, sodium acetate, and sodium hydroxide (acetic acid $K_a = 1.8 \times 10^{-5}$ and ammonia $K_b = 1.8 \times 10^{-5}$).

(a) Which chemicals will you use to make your buffer? Explain your choice; use chemical equations where appropriate.

(b) How much of each chemical will you need? Show calculations to support your answer.

(c) Outline the procedure you will follow to make your buffer. Include specific equipment and glassware you will use.

(d) How will you prove that you successfully prepared the buffer?

ADDITIONAL SUGGESTIONS FOR SECTION II, PART B

The following are some other suggestions for Section II, Part B that are not specifically tied to the 1999 version of the examination.

(1) A 0.2 M sulfuric acid is added to a 0.2 M solution of barium nitrate. Describe what happens and write an equation representing the reaction.

(2) A small piece of solid potassium is added to 500 mL of water in a beaker. The potassium fizzes, dances about, and bursts into flame.

(a) Write an equation representing the reaction.

(b) A drop of phenolphthalein solution is added to the resulting solution. What would you observe? Explain.

The panel also suggests that a useful addition would require students to identify reactions as examples of one or more of the following types of reactions: acid/base, oxidation/reduction, decomposition, combination, precipitation, gas evolution, double displacement, electron transfer, and proton transfer. (This list could be expanded or reduced.)

Appendix E

Research Agenda for Advanced Studies in High School Chemistry

The chemistry panel identified a number of topics on which research is needed with respect to advanced studies in high school chemistry:

1. How do students who take advanced courses in high school chemistry move through their college studies (e.g., choice of major, continued interest and enrollment in chemistry), and how well do they succeed compared with students who do not take these programs? Longitudinal data are needed to address these questions.

2. What are the actual costs for implementing, sustaining, updating, and upgrading advanced courses in the experimental sciences? Surveys of teachers are needed to determine actual costs.

3. Is there a difference in the academic success of students whose school districts spend more money on these programs (e.g., for staff development, materials, and modern equipment and facilities) compared with districts that spend less?

4. How much is information technology being integrated into advanced study courses, and what are the requirements for achieving such integration?

5. To what extent do the Advanced Placement (AP) and International Baccalaureate (IB) courses reflect current approaches to teaching and learning in introductory college courses?

6. How much variation exists in the granting of college credit and placement in courses to students who take advanced courses in high school?

7. What are the effects of the current ordering of prerequisite and advanced courses in science?

8. Do advanced programs favor some kinds of students over others?

9. What backgrounds, credentials, and professional experience characterize teachers who are involved with these programs? Do these differences translate into how well students learn and achieve in the courses?

10. What percentage of students who take AP chemistry take it as their first course in chemistry? How well do these students fare in the course and subsequently in college chemistry courses?

11. What proportion of students who take AP or IB chemistry do not take the examinations? What effect does the resulting lack of information about student learning have on the quality and quality control of the AP program in individual schools and on the AP program overall?

12. Are there advantages to having schools offer clusters of advanced study courses as opposed to isolated courses? What is the impact of not doing so (for example, in small high schools that can support only one or two advanced study courses that may not be connected with each other)?

13. Are there “critical masses” in the number of teachers in a school who teach advanced study courses? In other words, do differences in opportunities for isolated teachers to communicate with colleagues translate into differences in learning and achievement of their students?

14. Are there “critical masses” in the number of students who enroll in advanced study courses? Are students who enroll in such courses either individually (e.g., through distance learning courses) or in small numbers at an advantage or disadvantage relative to students who are enrolled in very large classes?

15. What percentage of schools have prerequisites or other screening procedures for entry into advanced study courses? Do more stringent requirements for entry into such courses translate into differences in scores on the respective assessments?

16. What kinds of physical facilities, equipment and instrumentation, and support for laboratories are available to teachers and students in advanced study programs in the experimental sciences? Do differences in the level and availability of such resources have an impact on student learning and performance?

17. Are there differences in student performance on advanced study examinations in districts or states that provide incentives to students to do well as compared with students in districts or states that do not offer these kinds of incentives?

Content Panel Report:

Physics

1

Introduction

The National Research Council's Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed a physics panel to provide advice on the effectiveness of and potential improvements to programs for the advanced study of physics in American high schools. Appendix A presents the parent committee's charge to the panel. The physics panel met twice (in May and July 2000) to address its charge from the parent committee. The panel was chaired by a member of the parent committee, who served as liaison to the committee and consolidated the panel's findings and recommendations into this report. Panel members included experienced college and university physics professors noted for their work in physics education, as well as high school physics teachers (for biographical sketches, see Appendix B).

To develop a framework for its recommendations, the panel began with a thorough discussion of recommended practices that it would expect to find in a good advanced high school physics program. Chapter 2 presents a summary of the panel's review. Using the model that emerged from that discussion, the panel evaluated the two dominant advanced high school programs—Advanced Placement (AP) and International Baccalaureate (IB)—to determine the extent to which they encourage the use of those recommended practices in their physics courses. The results of this evaluation are presented in Chapter 3, along with the panel's recommendations for improvements to both programs.

Although the panel lacked sufficient time to consider all possible alternatives to the AP and IB programs, it did consider one alternative approach, presented in Chapter 2. The panel recognizes that each high school is a unique environment with its own strengths and limitations. Thus there is unlikely to be a single advanced program that could reasonably be implemented with complete uniformity across the nation. Instead, the panel suggests that high schools and school districts offering advanced physics instruction adopt a program that has the general characteristics described in

Chapter 2 but is flexible enough to be implemented in a school's or district's specific context.

Chapters 4, 5, and 6 examine three topics of importance to the panel's review of advanced study programs in physics: Chapter 4 looks at the crucial role played by teaching and learning; Chapter 5 summarizes changing emphases in physics and their impact on advanced physics instruction; and Chapter 6 addresses the linkage between advanced high school physics programs and college physics programs. Each of these chapters includes the panel's specific recommendations in the respective area. Finally, Chapter 7 summarizes the panel's main findings and overall recommendations.

2

Recommended Practices for Advanced Physics Instruction

WHAT IS AN ADVANCED PHYSICS PROGRAM?

The term “advanced” is taken here to mean study that is substantially beyond the level of the physics required for high school graduation under the *National Science Education Standards (NSES)* (National Research Council [NRC], 1996). Although the goal of an Advanced Placement (AP) physics course is to substitute for a physics course that would otherwise be taken in college, that is certainly not the only possible reason for undertaking or offering an advanced program of study in high school. In some cases, traditional high school–level courses are simply not sufficiently challenging to interest the brightest students. In many cases, students undertake advanced study to enhance their college applications. In still other cases, students may be interested in particular areas of physics that are not covered in available high school–level courses (as discussed later in this chapter). Certainly, the particular program adopted by each high school will depend a great deal on exactly what goals that program is intended to meet.

PREREQUISITES FOR AN ADVANCED HIGH SCHOOL PROGRAM

The panel recognizes that the level of preparation of students entering advanced physics programs varies widely from high school to high school. Nevertheless, we believe that there are two fundamental prerequisites most entering students should meet:

- Prior to enrolling in an advanced physics course in high school, students should have studied the physics that is suggested as a requirement for high school graduation in the *NSES* (NRC, 1996). This requirement can be satisfied with the first year of a 2-year physics program. This is the approach adopted by the International Baccalaureate (IB) program (as discussed in

Chapter 3). If a 1-year advanced course is the first time that entering students encounter physics, the usual result is a packed schedule that allows too little time to develop the depth of understanding that is the fundamental goal of the program.¹

- Students should be fluent in mathematics through the precalculus level (see the discussion below). In particular, by the time they are ready to study advanced physics, students should be skilled in algebraic manipulation and have a firm grasp of basic trigonometry. Emphasis should also be placed on the use of proportions to solve problems, estimation skills, the use of international units, and scientific notation (powers of 10). Acquiring all necessary mathematical skills may well take several years of study before a student enters the advanced physics program. The panel encourages high school physics teachers to work closely with the mathematics departments of their schools to develop the necessary courses of instruction.

Mathematics is the language used to describe the fundamental laws of physics. Just as it is very difficult to teach physics to students who barely understand English (or the language of instruction), it is equally difficult to teach physics to students who do not “speak mathematics.” At the level of advanced physics study in high school, speaking mathematics consists primarily of facile manipulation of algebraic equations and an intuitive grasp of the significance of those equations. For example, students should have no doubt that linear relationships lead to straight-line graphs and that the presence of curvature in a graph implies that the relationship cannot be linear.

While knowledge of calculus is unquestionably helpful in the study of advanced physics, it is not absolutely essential. Ideas such as the derivative and integral can be introduced in physics classes by discussing the slope of tangent lines and the area under curves. However, the level of mathematical skill of students may well play a role in the selection of optional physics topics (as discussed later in this chapter).

THE MOST IMPORTANT OBJECTIVES

There was strong consensus within the panel that the most important objectives for advanced study in high school physics are not tied to particular topics in physics. The panel is far more concerned with promoting more general dispositions, abilities, and habits of mind. In particular, advanced study in physics should help students further develop the following:

¹The panel acknowledges that there are circumstances under which it is appropriate for students to take advanced physics as a first-year physics course. This may apply to exceptionally talented students or to students in schools where scheduling considerations leave no reasonable alternative. Nevertheless, most students would be well advised to begin their study of physics with a sound high school-level course.

- Excitement, interest, and motivation for further study in physics
- Facility with mathematics as a means of communicating, examining, and refining ideas
 - Scientific imagination and creativity
 - Scientific habits of mind or the abilities and inclinations:²
 - To look for and examine assumptions hidden in the student’s own and others’ reasoning
 - To seek precision and clarity in forming and communicating ideas, including the use of mathematics
 - To design and conduct empirical investigations to answer scientific questions
 - To identify and reconcile inconsistencies between the student’s understanding and observations
 - To develop, implement, test, and revise models of physical phenomena
 - To develop and learn to work within a framework of theoretical principles

DESIGNING A CURRICULUM TO MEET THESE OBJECTIVES

The Central Role of Newtonian Mechanics

Although the objectives listed in the previous section can be met through a thorough study of many different areas of physics, some commonality among programs is clearly desirable, especially when advanced programs serve as substitutes for physics courses in college. Given the central role of Newtonian mechanics in physics, both historically and conceptually, the panel recommends that any advanced study of physics include Newtonian mechanics. Mechanics provides an ideal framework for achieving the objectives cited above. At the same time, familiarity with mechanics is universally expected of students entering college who have completed an advanced high school physics program.

Maximizing the Commonality of Advanced Programs in Newtonian Mechanics

Because the study of Newtonian mechanics serves as the foundation of any good program of advanced physics study, the panel recommends that

²We note that the Theory of Knowledge course included in the IB program (see Chapter 3) deals with the habits of mind listed here. This is an advantage of the IB program; since it is a program rather than a course, one teacher need not do everything.

the set of topics addressed be standardized as much as possible across the nation. While the exact details of such a nationwide mechanics syllabus can be agreed upon at a future time, the panel makes the following two recommendations:

- The syllabus should include the study of rotational dynamics. It is important for students to learn to apply the laws of mechanics to extended bodies, not just point particles. Not only is the physics content important, but the study of rotational dynamics also presents substantial intellectual challenges that help prepare students for the challenges of their future higher education.
- There should be no distinction made between the study of mechanics with and without calculus. Whether or not the mathematical background of the students includes calculus, the concepts necessary for physics [e.g., $(\lim/\Delta t \rightarrow 0) \text{ of } (\Delta x/\Delta t)$] can and should be introduced.

The primary goal of the study of Newtonian mechanics is to develop conceptual understanding, rather than the ability to perform complex mathematical manipulations. For example, it is not necessary for advanced high school students to learn how to calculate the moment of inertia of a cylinder about some given axis, but it is important for them to understand rotational kinetic energy and angular momentum.

The Role of Calculus in the New Common Mechanics Unit

The panel stresses that the new mechanics unit recommended above is by no means a noncalculus introduction to mechanics. Indeed, the concepts of calculus are absolutely essential to the physics subject matter. Specifically, the panel emphasizes the following points:

- Teachers with qualified students are encouraged to use formal calculus. Such students are eager to apply their mathematical prowess and should be encouraged to do so. It is likely that such students would continue their calculus-based study of physics in a second-semester course such as AP Physics C Electricity and Magnetism.³

³AP Physics C Mechanics and AP Physics C Electricity and Magnetism are one-semester calculus-based courses, each leading to its own separate AP examination. AP Physics B is a two-semester noncalculus course leading to a single comprehensive AP Physics B examination. For a detailed discussion of the AP Physics program, see Chapter 3.

- The final examination for the new unit would not require students to use formal calculus. In all other respects, however, the new examination should be at about the same level as the current exam for AP Physics C Mechanics. This recommendation is in harmony with the current trend on that examination: less reliance on technical mathematics and increasing emphasis on conceptual physics (see Chapter 3).
- The final examination for the new unit would test students' knowledge of the concepts of both differential and integral calculus required to develop the physics. For example, students would be required to know that instantaneous velocity can be obtained as the slope of the graph of displacement versus time and that the work done by a force that varies as a function of position can be obtained from the area under the force curve.

Comparison of the New Mechanics Unit with Current AP Mechanics

Students who today would study AP Physics Mechanics C would find the new unit to be very much in line with their expectations for that course. There would be less emphasis on formal mathematics and more on conceptual understanding, but the general level of the treatment of the physics would be the same as that of current AP Physics C Mechanics. All the important physics currently found in AP Physics C Mechanics would still be covered and tested on the final examination.

Students who today would study AP Physics B would find the new mechanics unit to be a more comprehensive and in-depth treatment of the subject than that found in current Physics B courses, primarily because of the inclusion of rotational dynamics. Therefore, the primary effect for AP Physics students of the creation of a common mechanics unit as recommended by the panel would be to raise the standards in mechanics for Physics B to the level of Physics C.

Coverage of Other Areas of Physics

The breadth of material included in introductory college courses almost always requires rapid, superficial treatment. Unfortunately, the emphasis on breadth to the exclusion of depth is also growing at the secondary level, as more states are adopting encompassing frameworks and standards for science instruction. The panel believes, however, that for students to appreciate physics as a field of inquiry, it is more important for them to develop depth of understanding in the areas they study than to study any particular areas. The amount of additional material beyond Newtonian mechanics that can be covered in a particular course depends on its length. For a 1-year

program, the panel believes strongly that students should study at most one other major area of physics.⁴ In a 2-year program, the number of topics can be increased as long as the essential goal of depth of understanding is attained.

Additional Areas That Match Instructors' Talents and Resources

The panel believes that advanced physics programs should be able to choose from among various options the extra topics that best meet their needs. We offer the following possible optional topics for illustration only; a detailed list of options and a syllabus for each need to be carefully developed:

- Electricity and magnetism/circuits
- Models of light and sound (geometrical optics, mechanical waves, physical optics)
 - Complex systems (thermal and statistical physics, computer-assisted conceptualization, chaos)
 - Atomic, nuclear, and particle physics

Again, we are not proposing here the specific makeup of these other options; we are proposing that they be developed. In each case, physics teachers and students would be motivated to pursue greater depth of coverage in a limited area. We note that the ability to develop such options gives advanced high school instruction the flexibility needed to address emerging areas of physics, as discussed below.

Second Semester Options

In this section, we provide additional detail on some optional curricula that could be used in the second semester of an advanced physics program. In describing these options, we assume that students have already completed the new common mechanics unit discussed above. Our goal is not to specify these curricula completely; that is a task for other organizations, such as the College Board and the International Baccalaureate Organisation (IBO). Rather, the brief summaries below are intended to give the reader a better understanding of the overall content and goals of these example courses.

⁴The panel is aware that many current AP Physics C programs spend the entire academic year on mechanics. We have no objection to this practice, which may well provide the extra time necessary for those students to achieve the depth of understanding that is the central objective of advanced physics study.

AP Physics C Electricity and Magnetism. This existing semester course is already familiar to many readers; it is the usual follow-up for students who take the current AP Physics C Mechanics course during the first semester. The content of the course is specified in the 2000/2001 edition of the *Advanced Placement Course Description: Physics*, published by the College Board (1999a) and known as the Acorn Book. (See Chapter 3 for a detailed discussion of the AP Physics program.)

The course is highly mathematical and covers Maxwell's equations in integral form. There are numerous applications of calculus, as well as an introduction to direct-current circuits. Capacitance and inductance are introduced, and the time dependence of currents and voltages in simple circuits is studied. The panel recommends decreased emphasis on the technical mathematical details and more emphasis on conceptual understanding. However, there is nothing to prevent this curriculum from being used as a second-semester option in its present form.

Biomedical Physics. The IBO has already defined a syllabus for the study of this topic in the *IB Diploma Programme Guide: Physics* (IBO, 2001). (See Chapter 3 for a detailed discuss of the IB physics program.) This noncalculus course covers the following major topics:

- Fluid statics, fluid flow, and the physics of the cardiovascular system
- Rotational statics, with application to the muscular-skeletal system
- Hearing—normal function, defects, and correction
- Radiation—types, sources, properties, and detection
- Medical imaging
- Biological effects, hazards, dosimetry, and diagnostic uses of radioactive sources

The course is currently designed to be covered in 30 hours, or approximately half a semester. Therefore, if the course were used as a semester option, several of these very interesting topics could be covered in greater depth, consistent with the fundamental goal of achieving deep conceptual understanding.

Special and General Relativity. This is another area for which the IBO has already created a detailed syllabus for a noncalculus course. The major topics covered by that syllabus include the following:

- Frames of reference and Galilean relativity
- Postulates and fundamental concepts of special relativity
- Historical context and experimental support for special relativity
- Postulates and fundamental concepts of general relativity
- Experimental support for general relativity (IBO, 2001)

Once again, the course is designed to be covered in 30 hours. However, this rich and intensely interesting subject lends itself to in-depth study in a myriad of ways. Indeed, a relativity option is likely to generate excitement and motivation for further study in physics—a key goal of advanced physics study cited earlier.

Fields at the Forefront of Current Physics Research as Optional Topics

One of the frustrating aspects of conventional physics instruction for new students is that they must spend years studying classical physics before they learn about fields at the forefront of current physics research. The teacher of an advanced high school program might well choose to use the time available after completing the required mechanics foundation to explore one of these fields.

Unlike conventional advanced physics study, which attempts to accelerate students in classical physics, the goal here would be advancement by enrichment. Such enrichment is an excellent way to generate enthusiasm for further study in physics, which, as noted above, is a key goal of any advanced high school physics program.

Examples of such enrichment might include a course on special and general relativity along the lines of Taylor and Wheeler's (2001) *Spacetime Physics*; a course that looks at quantum mechanics from a qualitative point of view; a course investigating nonlinear dynamics; a course in electricity and magnetism using a laboratory-based approach, such as the ZAP! Program by Morrison, Morrison, and Pine (1996); and a course in the history of particle physics, from the discovery of the electron to the confirmation of quarks. The intent of such courses would be to explore the topic with a depth and breadth commensurate with the mathematical sophistication of the students taking the course and the expertise of the teacher.

There are several potential advantages to this type of enrichment:

- The topics involved would often be exciting and speculative, appealing to students' taste for the exotic, and could motivate students to work and think at a more sophisticated level.
- Students would have more opportunities to exercise their critical and creative abilities than is the case in the highly defined and codified curriculum typical of the present AP and IB programs.
- Students could be better able to grasp the big picture of what is taking place in current physics research and to decide whether they want to be a part of that effort.
- Some course designs could provide real opportunities for long-term student-designed experiments and open-ended investigations.

- Students and teachers would have an incentive to use the Internet to identify research being done, to try out simulations, and to participate in distance learning opportunities or in organized forums addressing particular course topics in which researchers might cooperate as participants.
 - Students and teachers might have an incentive to work with professionals from outside the school with expertise appropriate to the course, promoting both learning and broader collegial connections. College courses may already exist that could be adapted to create such courses.
- There are also potential difficulties with such undertakings:
- The offerings might have to compete with more conventional advanced courses for a limited number of students.
 - Colleges would be unlikely to grant credit or placement for these course offerings, since their content probably would not match that of college courses.
 - Schools might not be willing to allocate the human and material resources needed to develop such courses.
 - Teachers with sufficient expertise to teach the courses might not be available.

In addition to the above difficulties, no mechanism currently exists to validate that these course offerings provide the appropriate depth of understanding for advanced high school physics programs. Development of a mechanism for reviewing, certifying, and disseminating curricula and for training and certifying teachers in the use of such curricula would therefore be an essential part of advancement by enrichment. One possible approach would be for the American Physical Society and the American Association of Physics Teachers (AAPT) to establish a joint committee to operate as a Clearinghouse for Advanced Programs in Physics (CAP). Curriculum developers would submit proposed curricula to the CAP, which would then review them for quality of physics content, pedagogy, and interest to students. A curriculum passing the review would be certified as a CAP-Physics curriculum. Curriculum submitted during development might be issued a provisional certificate and reviewed again when in final form.

Once a curriculum had been granted a certificate, its developers could offer summer training institutes for teachers, subject to standards for such institutes issued by the CAP. Such standards might mandate a minimum time for the training and the makeup of the instructional staff. Teachers that completed the training satisfactorily, which might well involve passing a final examination on content, would be certified to offer the course in their schools. A school offering such a course, taught by a certified instructor, would be able to indicate the course on student transcripts as a CAP course.

Since CAP courses would not be designed to substitute for college courses, the CAP would not need to operate a testing program. It would, however,

serve as an information source on available certified curricula and on summer institute programs for teacher certification. On the other hand, curriculum development groups might wish to have their own testing program, and test data could serve as additional evidence that a curriculum was suitable for CAP certification.

The key advantage of the CAP concept is that it would bring together many existing programs rather than having them continually reinvented by different groups. Most current curriculum projects that would be suitable for submission to the CAP already have teacher training provisions. The CAP would add nationally recognized certification of quality and disseminate certified curricula to schools across the nation.

Inclusion of Meaningful, Challenging, Real-World Experiences

Science at its heart is the process of how we come to know about and understand the physical world around us, including how living things interact with and are part of that world. What distinguishes science from other ways of thinking is reliance on evidence about the physical world and the importance of reproducible, principled consistency in judging the truth and utility of conjectures, laws, and theories. The panel strongly believes that all science courses at all levels—including advanced science courses in high schools—should include a significant component of experience with real-world phenomena and the way scientific conceptions are tested against observations of those phenomena. The panel acknowledges that in practice the interplay between theory and experiment is often complex. The important point is that science requires both components, and science instruction should reflect that interplay.

At the advanced high school physics level, students should already have had considerable experience with these activities in earlier physics and physical science courses⁵ in the form of laboratory exercises, demonstrations, and perhaps even independent investigations. The panel believes that advanced physics courses should provide additional experiences for students in formulating their own conjectures and explanations, as well as in making the connections between real-world phenomena and the concepts, principles, and theories developed by the scientific community.

⁵As noted earlier, there are special circumstances under which it may be appropriate for students to study advanced physics as a first-year physics course. In such cases, students may have no previous experience with laboratory physics, although it is highly likely that they will have laboratory experience in other sciences. It is the responsibility of the instructor to design the laboratory portion of the course to reflect prior student experience.

What form should these additional real-world experiences take? Evidence⁶ indicates that traditional “cookbook” methods of laboratory instruction, in which students follow narrowly defined procedures to verify well-known principles, have little effect on students’ conceptual understanding; on the other hand, substantial improvements in understanding are possible through rigorous, interactive laboratory experiences. Although much has been made of the need for “hands-on” activities in science, it is clear that what really matters is not “hands-on” but “minds-on.” Cookbook labs are ineffective because students typically do very little thinking while they are working their way through the list of step-by-step instructions. Cookbook labs are mind-numbing experiences that lead students to describe their laboratory work as boring or a waste of time (NRC, 1997b). Indeed, in view of the fact that the time spent doing cookbook labs could be spent doing something more productive, it is doubtful that doing cookbook labs is better than doing no laboratory work at all.⁷

The research evidence against cookbook labs is not overwhelming, but we know of no research in their favor. The panel believes that the issue should be looked at from this point of view: What evidence is there that cookbook labs are of sufficient value to justify the enormous amount of time spent on them in physics programs across the nation? As far as we know, no evidence comes anywhere close to justifying this huge investment of effort.

Experimental work in advanced courses should provide experience with the way scientists use experiments—both for gathering data to build theoretical models and for exploring the applicability of these models to new situations. To that end, exploration of phenomena should generally precede and motivate the formal introduction of theoretical concepts. Moreover, students should make as many scientific decisions as possible, from the conception and design of the experiment all the way through the analysis, presentation, and critical review of the results.

The panel urges teachers of advanced physics courses to consider using a wide range of experiences, including the following (also see Box 2-1):

- Open-ended labs that require students to make decisions about what to observe, how to observe it, and how to interpret the data
- Labs that focus on allowing students to confront preconceptions and reconcile them with actual observations, with less emphasis on numerical data acquisition and analysis

⁶An excellent discussion of effective laboratory instruction can be found in *Science Teaching Reconsidered* (NRC, 1997b, pp. 16–20).

⁷In the AP Physics Video Conference of November 10, 2000, cookbook labs were labeled as the lowest of five levels of lab work. The hope was expressed that AP physics students would rapidly progress to higher levels in which they would take increasing responsibility for the design and analysis of experiments.

BOX 2-1 Useful Resources for Developing Real-World Experiences

Although by no means exhaustive, the following is a list of some resources that members of the panel have found particularly helpful in developing meaningful real-world experiences. More information about many of these resources is given in Chapter 4:

- Edge, R.D. (1987). *String and sticky tape experiments*. College Park, MD: American Association of Physics Teachers.
- Sokoloff, D.R., Laws, P. W., and Thornton, R.K. (1994). *Real time physics: Active learning laboratories: mechanics*. Medford, MA: Tufts University.
- Sokoloff, D.R., Laws, P. W., and Thornton, R.K. (1997). *Real time physics: Active learning laboratories: Electric circuits*. Eugene, OR: Department of Physics, University of Oregon.
- Physics Teaching Resource Agents (PTRA) materials: available at the AAPT Web site.⁸
- Chabay, R.W., and Sherwood, B.A. (1999). *Electric and magnetic interactions*. New York: Wiley.
- CASTLE curriculum materials and experiments (capacitors, light bulbs, and batteries) (available through Pasco Scientific, Roseville, CA).
- Steinber, M., and Wainwright, C.L. (1993). Teaching electricity with models—The CASTLE Project. *Physics Teacher*, 31, 353.

- Demonstrations that encourage students to predict what is going to happen and then follow up with discussion that reconciles predictions and observations
- Take-home labs that can be done with relatively simple equipment and everyday items
- Exercises that work with data available on the Internet (e.g., data on sunspots gathered over many years as an indicator of periodic cycles in sunspot activity)

The panel would argue that a specific list of experiments is not useful; there are too many variations in the availability of time and equipment for such a list to be helpful. Both the College Board and the IBO provide lists of

⁸Further information can be found by going to <http://www.aapt.org> [4/17/2002] and clicking on Programs and then PTRA.

labs that are commonly used in advanced secondary school physics courses, as well as in introductory college and university physics courses. Those lists can serve as a rough guide for teachers, although innovation is certainly to be encouraged. The panel also recommends that teachers of advanced courses be familiar with the AAPT's position papers on *The Role of Laboratory Activities in High School Physics* and *The Goals of the Introductory Physics Laboratory*, which describe aspects of the goals of experimental work in more detail.⁹

The way the experience is designed is more important than the specific topic. For example, a lab dealing with pendulum motion could be constructed as a rote exercise in data gathering to verify the dependence of the period of the pendulum's oscillatory motion on the length of the pendulum, but it would be better to design the experience as scientific inquiry. For example, the teacher might point out that some recent speculations about a so-called "fifth fundamental force" or extra space-time dimensions for gravity predict that the period of the pendulum motion should depend on the nature of the material of the pendulum bob—iron might behave differently from brass. The teacher might then ask what measurements should be carried out to test that idea and how well those measurements can be used to reject or confirm the idea. Still better would be a lab in which students would play with some pendulums first and then themselves come up with questions to ask about pendulum motion.

USE OF ASSESSMENTS THAT MEASURE DEPTH OF UNDERSTANDING

Assessments are a very important feature of any advanced physics program. Scoring well on a final examination is a tangible goal that both students and teachers can strive to achieve. Success on such examinations leads to feelings of triumph and looks good on college applications. In many cases, examination scores are also a major component of the school administration's evaluation of teacher performance.

Because of the high stakes involved, it is too often the assessments, rather than educational goals, that drive the instructional process. A prime example is the AP Physics B examination with its vast coverage of subject matter (see Chapter 3). In view of this fact, it is imperative that the assessments used accurately measure depth of understanding, the primary goal of advanced physics instruction. Unless the assessments encourage and reward students and teachers for exploring physics deeply in the ways described

⁹These papers are available at the AAPT Web site—<http://www.aapt.org> [4/23/02]—under "AAPT Statements and Policies."

above, they will not do so; instead, they will do what is necessary to score well on the assessments. Ensuring that tests emphasize conceptual understanding is an important way to encourage better teaching practices.

In the next section, we offer some general recommendations for creating desirable written examinations. Written examinations are the most practical means of assessing the performance of a large number of candidates but are certainly not the only means. In particular, we draw the reader's attention to the internal assessment component of the IB physics program discussed in Chapter 3.

Designing Good Written Examinations

A good written examination in an advanced physics program should:

- **Emphasize conceptual questions, rather than mathematical techniques.** Here we are not distinguishing questions that are conceptual from those that are mathematical; conceptual questions may well involve mathematics. Rather, we are distinguishing questions that assess conceptual understanding from those that assess mainly technical mathematical skill.

- **Require explanation of the candidate's reasoning.** The goal of an advanced course is not just to provide the correct answer but also to communicate the reasoning process that leads to that answer.

- **Eliminate free-response questions that lead students through arguments by means of multiple interdependent parts.** Instead, shorter questions that call for original reasoning in a complex unfamiliar setting are desirable. Open-ended questions posed in a real-life setting can help strengthen the connection between physics and the world around us and are thus recommended.

- **Construct multiple-choice questions that reflect common student misconceptions.** Research is required to determine adequate distracters (incorrect multiple-choice answers). Ideally these distracters should be obtained from answers given previously by students to free-response questions. Additional improvements include multiple-choice questions that have more than one correct answer (multiple-completion questions) and multiple-choice questions that require not only the selection of a correct answer but also the selection of a correct justification.

- **Allow sufficient time for most well-prepared students to complete every question.** Emphasis must be placed on what a student knows—not how quickly the student can recall and use that knowledge.¹⁰

¹⁰We are not suggesting that AP physics examinations be untimed. We simply want to provide sufficient time for well-prepared students to demonstrate their knowledge without being rushed.

- **Use innovative kinds of questions that probe depth of understanding.** Many alternative forms of assessment exercises exist, and some of these have been shown to be valuable. For example, students could be asked to score or rank a number of student solutions to a free-response question. Such an exercise would require not only understanding the question posed but also distinguishing among different models and recognizing the correct one.

- **Written examinations cannot accurately assess laboratory skills and should not attempt to do so.** However, questions involving analysis and interpretation of data are both reasonable and desirable. In addition, students can be asked to outline the design of simple experiments based on their general knowledge. Since there is no required list of experiments that all students must perform, such questions must not depend too strongly on the specifics of any particular experimental technique. Recent AP physics examinations contain many good examples of questions that satisfy these criteria.

Need for Improved Scoring Techniques

The scoring of written examinations must emphasize the evaluation of student understanding. A rigid scoring rubric in which points are awarded for highly specific correct responses to small parts of each question is not appropriate because it reduces the reader's ability to respond to student thinking (both correct and incorrect) not anticipated by the rubric. Rather, the reader should evaluate the student's response as a whole. A maximum score should be given only for complete and clear physical reasoning leading to the correct conclusions. Lower scores should be given for missing or erroneous reasoning, even if the conclusions reached are correct.

To understand this recommendation, it is important to distinguish between the allocation of maximum possible scores to different parts of the test and scoring rubrics of the type we decry. It is surely reasonable to allocate 10 points to problem 1, 15 points to problem 2, and so on. Similarly, it is reasonable to further subdivide the maximum possible credit for problem 1 among parts 1a, 1b, and 1c, as long as these parts are truly independent of each other. What is not reasonable, in our view, is to allocate 1 point for the statement of Newton's second law, 1 point for solving the resulting equations, 1 point for the numerical answer, and so on. Such rigidity makes it impossible to properly evaluate the student's reasoning, which is what we should be most interested in. Similar difficulties arise if parts 1a, 1b, and 1c are interdependent, since that will often allow students to answer the parts in many different orders and a wide variety of ways. If a question contains multiple interdependent parts (a practice against which the panel has argued above), it is better to evaluate the entire question as a whole.

To be clear, we are not advocating the abolition of all standardization of grading. Maintaining consistency in grading is indispensable to the fairness of the examination. Rather, we are advocating more flexible rubrics of the kind given on the College Board Web site in, say, U.S. History or English Literature. General guidelines are desirable; rigid rules for awarding each point are not. Moreover, we applaud the care shown by both the AP and IB programs in monitoring the consistency of the grading process and would expect such monitoring to continue.

Importance of High Standards for Success on Final Examinations

If the smaller and more manageable curriculum proposed earlier in this chapter were adopted, we would expect successful students to know the material in that curriculum thoroughly. Therefore, we recommend high standards of performance on the final examination for these students. While it is beyond the scope of the panel's work to propose specific standards, we believe the standards for awarding grades should be substantially higher than those currently in use by the two dominant programs. Currently, students can earn a grade of 5 in AP Physics B with raw scores that range anywhere from 106 to 180 points.¹¹ The panel is unanimous in asserting that this range is too broad; students who earn scores at the upper end of the range are better qualified than those at the lower end of the range. While this wide score range might serve a purpose in the current AP Physics program by allowing teachers to focus on some aspects of the curriculum at the expense of others without their students being penalized, a narrower score range would be more appropriate in the context of the more manageable curriculum proposed by the panel.

Less is known about the marking of IB assessments than about the scoring of AP examinations. However, the range of scores, particularly at the top, raises similar concerns about IB standards. The panel notes that IB students can obtain top marks on their examinations by earning 57 percent of the points for a 6 and 70 percent of the points for a 7.¹²

Additional evidence that standards for success on AP physics examinations should be higher can be found in an abstract by Howard Wainer of the Educational Testing Service that appeared recently (March 2001) on the College Board Web site. It states that students who were allowed to skip their first course in physics by virtue of success on the AP examination did not do

¹¹Data based on the *1998 Released Examinations* published by the College Board (1999b).

¹²The IB figures were estimated from information supplied by the IBO to the panel in the *subject report* for May 1999 (IBO, 1999b).

as well as students without AP experience in their second college physics course. This is particularly troubling in view of the fact that students with AP experience usually are among the most successful academically and normally outperform non-AP students. In fact, according to the abstract, AP students outperformed non-AP students in all but three disciplines: physics, economics, and U.S. government.

3

Extent to Which the AP and IB Programs Implement Recommended Practices

This chapter presents a critical review of the Advanced Placement (AP) and International Baccalaureate (IB) programs in light of the recommended practices set forth in Chapter 2. Before proceeding, it is important to make note of the differing backgrounds and goals of AP and IB physics.

Today, the AP and IB physics programs constitute the two most significant factors in defining what is meant by advanced study of physics in the United States. Most students entering the postsecondary education system each year who are identified as having completed an advanced physics course have participated in these two programs.

The reasons for the creation of the two programs were substantially different, and this led naturally to substantial differences in their approaches to advanced physics instruction. All judgments made in any comparison of the programs must be viewed through the lens of their distinctive histories and present structures.

THE AP PHYSICS PROGRAM

In this section, we respond directly to the questions under the panel's charge (see appendix) related to curriculum and assessment for the AP physics program. Where necessary, we distinguish between AP Physics B, a broad survey course without calculus, of the type often taken by students majoring in biology or health-related fields; and AP Physics C, a calculus-based introductory course in mechanics and electricity and magnetism, of the type generally taken by students concentrating in the physical sciences or engineering.

We note at the outset that both AP Physics B and AP Physics C are 1-year courses that are often taken by high school students as a first physics course,¹³

¹³The College Board supplied the panel with the results of the background questions asked of the 1998 AP physics examination candidates. Approximately two-thirds of the 24,000

although that is not recommended by the College Board. As noted in Chapter 2, many students spend their entire academic year studying just the mechanics portion of AP Physics C. The additional time available makes it more reasonable to use advanced mechanics as a first course in physics.

Degree to Which the Factual Base of Information Provided by the AP Curriculum and Related Laboratory Experiences Is Adequate for Advanced High School Study in Physics

There is no question that the factual base of information provided by the AP physics curriculum and related laboratory experiences is fully adequate for a good advanced program. This factual base for AP physics is determined by the College Board through a poll of a large number of colleges to determine the content of their first-year physics courses (College Entrance Examination Board [CEEB], 2001).

The College Board does not mandate any specific laboratory experiences. Instead, it makes the general statement that in introductory college courses approximately 20 percent of the credit awarded can be attributed to laboratory performance (CEEB, 2001, p. 10). In addition, the effectiveness of laboratory experiences is greatly dependent on the particular implementation of laboratory instruction in each individual high school (see Chapter 2). Therefore, it is impossible to determine the adequacy of laboratory experiences definitively for the entire AP physics program.

Extent to Which the AP Curriculum and Assessments Balance Breadth of Coverage with In-Depth Study of Important Topics in Physics

AP Physics C is a reasonable-sized 1-year physics course with respect to the content covered. It is, in fact, one implementation of the model presented in Chapter 2—Newtonian mechanics with an electricity and magne-

Physics B candidates had taken only two or fewer semesters of physics in high school prior to attempting the examination. The situation is reversed for Physics C, with about three-fifths of the candidates having taken three or more semesters of physics prior to the examination. The number of 1998 Physics B candidates was approximately twice the number of Physics C candidates, so that well over half of all 1998 AP physics candidates had taken two or fewer semesters of physics prior to attempting their examinations. About half of the Physics C candidates (6,000 students) took only the mechanics and not the electricity/magnetism exam. About half of this mechanics-only group had taken two semesters or fewer of physics in high school. This suggests that a substantial number of students are using AP Physics C Mechanics as a first-year physics course.

tism option. Indeed, students are examined separately on mechanics and electricity and magnetism and can choose to take either or both examinations. AP Physics C is appropriately balanced between breadth and depth. However, it makes mathematical demands that are not appropriate for all students.

By contrast, AP Physics B is a gigantic course that is nearly impossible to cover properly in a single year. It encourages cursory treatment of very important topics in physics in a way the panel believes is inappropriate for an advanced high school course. Such a large amount of material should clearly be spread over 2 years. If the recommendations presented in Chapter 2 were implemented, AP Physics B would cease to exist as a 1-year program.

We emphasize that an advanced physics curriculum should focus more on conceptual understanding and less on mathematical manipulation. For example, it is much more important that students understand intuitively the consequences of shorting out a circuit element than that they be able to solve numerous simultaneous linear equations obtained from Kirchhoff's laws. To better illustrate the difference between these two kinds of knowledge, Box 3-1 presents a case study done by Professor Eric Mazur of Harvard University, a member of this panel (Mazur, 1997).

Degree to Which AP Physics Courses Are Organized Around Key Concepts to Promote Conceptual Understanding

As discussed in Chapter 2, Newtonian mechanics should provide the conceptual foundation for all advanced physics programs. Both AP courses have a substantial mechanics component, but AP Physics C Mechanics, with its coverage of rotational dynamics, is closer to the Newtonian mechanics foundation recommended for all advanced high school physics programs in Chapter 2. On the other hand, we believe that the current AP Physics C Mechanics curriculum contains excessive mathematical complexity that should be eliminated in favor of increased emphasis on conceptual understanding.

Degree to Which the AP Physics Curriculum and Related Laboratory Experiences Provide Opportunities for Students to Apply Their Knowledge to a Range of Problems in a Variety of Contexts

The AP curriculum provides ample material for problem solving. Indeed, problem solving is an indispensable part of any advanced physics course. However, the range and variety of contexts of problems can vary

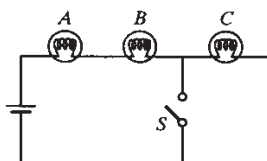
BOX 3-1 Excerpt from *Peer Instruction: A User's Manual*

Introduction

MEMORIZATION VERSUS UNDERSTANDING

To understand these seemingly contradictory observations, I decided to pair, on subsequent examinations, simple qualitative questions with more difficult quantitative problems on the same physical concept. An example of a set of such questions on dc circuits is shown in Figure 1.1. These questions were given as the first and last problem on a midterm examination in the spring of 1991 in a conventionally taught class (the other three problems on the examination, which were placed between these two, dealt with different subjects and are omitted here).

1. A series circuit consists of three identical light bulbs connected to a battery as shown here. When the switch S is closed, do the following increase, decrease, or stay the same?



- (a) The intensities of bulbs A and B
 - (b) The intensity of bulb C
 - (c) The current drawn from the battery
 - (d) The voltage drop across each bulb
 - (e) The power dissipated in the circuit
5. For the circuit shown, calculate (a) the current in the $2\text{-}\Omega$ resistor and (b) the potential difference between points P and Q .

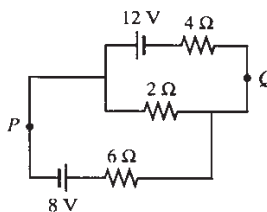


Figure 1.1 Conceptual (top) and conventional question (bottom) on the subject of dc circuits. These questions were given on a written examination in 1991.

Notice that question 1 is purely conceptual and requires only a knowledge of the fundamentals of simple circuits. Question 5 probes the students' ability to deal with the same concepts, now presented in the conventional numerical format. It requires setting up and solving two equations using Kirchhoff's laws. Most physicists would consider question 1 easy and question 5 harder. As the result in Figure 1.2 indicates, however, students in a conventionally taught class would disagree.

Analysis of the responses reveals the reason for the large peak at 2 for the conceptual question: Over 40% of the students believed that closing the switch doesn't change the current through the battery but that the current splits into two at the top junction and rejoins at the bottom! In spite of this serious misconception, many still managed to correctly solve the mathematical problem.

Figure 1.3 shows the lack of correlation between scores on the conceptual and conventional problems of Figure 1.1. Although 52% of the scores lie on the broad diagonal band, indicating that these students achieved roughly equal scores on both questions (± 3 points), 39% of the students did substantially worse on the conceptual question. (Note that a number of students managed to score zero on the conceptual question and 10 on the conventional one!) Conversely, far fewer students (9%) did worse on the conventional question. This trend was confirmed on many similar pairs of problems during the remainder of the semester: Students tend to perform significantly better when solving standard textbook problems than when solving conceptual problems covering the same subject.

This simple example exposes a number of difficulties in science education. First, it is possible for students to do well on conventional problems by memorizing algorithms without understanding the underlying physics. Second, as a result of this, it is possible for a teacher, even an experienced one, to be completely misled into thinking that students have been taught effectively. Students are subject to the same misconception: They believe they have mastered the material and then are severely frustrated when they discover that their plug-and-chug recipe doesn't work in a different problem.

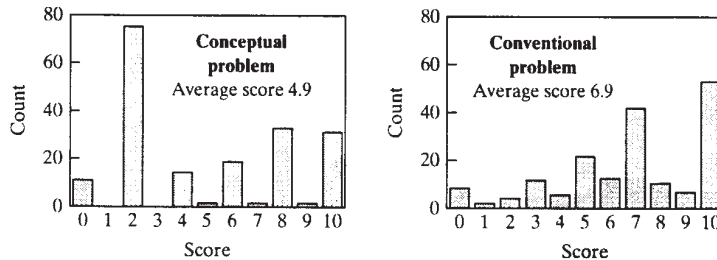


Figure 1.2 Test scores for the problems shown in Figure 1.1. For the conceptual problem, each part was worth a maximum of 2 points.

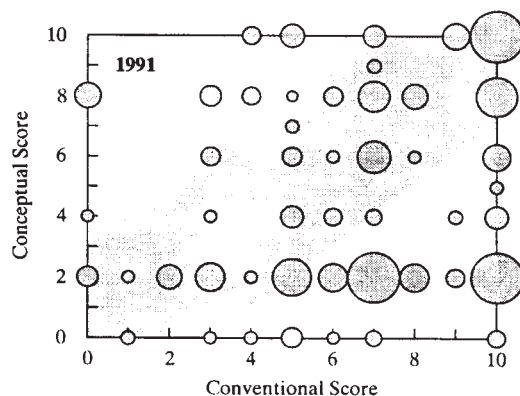


Figure 1.3 Correlation between conceptual and conventional problem scores from Figure 1.2. The radius of each datapoint is a measure of the number of students represented by that point.

Clearly, many students in my class were concentrating on learning “recipes,” or “problem-solving strategies” as they are called in textbooks, without considering the underlying concepts. Plug and chug! Many pieces of the puzzle suddenly fell into place:

- The continuing requests by students that I do more and more problems and less and less lecturing— isn’t this what one would expect if students are tested and graded on their problem-solving skills?
- The inexplicable blunders I had seen from apparently bright students— problem-solving strategies work on some but surely not on all problems.
- Students’ frustration with physics—how boring physics must be when it is reduced to a set of mechanical recipes that do not even work all the time!

SOURCE: Mazur (1997).

substantially among specific implementations at different high schools. Therefore, the opportunities advanced students have to apply their knowledge to problems in a variety of contexts depend upon the particular AP physics program in which they are enrolled.

Extent to Which the AP Physics Curriculum and Related Laboratory Experiences Encourage Students and Teachers to Make Connections Among the Various Disciplines in Science and Mathematics

The connection between physics and mathematics is very strong, and both AP physics courses call upon students to use their mathematical skills to the fullest. Indeed, it is not unusual for students to say after they have taken AP physics that they appreciate the great value of mathematics for the first time.

On the other hand, the AP physics program does not encourage students and teachers to connect physics with other areas of science. Rather, such connections are made at the discretion of individual teachers or high schools. These decisions may be shaped by such factors as opportunities for departments to interact or plan courses together or by the textbooks selected for the course.

Laboratory experiences can indeed be used to make interdisciplinary connections. Yet because the nature of laboratory experiences varies substantially among the implementations of AP physics at different high schools, it is impossible to answer this question for the AP physics program as a whole. For a thorough discussion of the importance of laboratory experiences in advanced physics study, see Chapter 2.

Extent to Which Final Assessments in AP Physics Measure or Emphasize Students' Mastery of Content Knowledge

The coverage of topics on the Physics B examination is excessively broad. The coverage of topics on the Physics C examination is appropriate, although the nature of the questions (discussed below) may encourage instructional approaches that emphasize mathematical technique rather than conceptual understanding. In that case, students may experience the course as a nonhierarchical litany of facts and formulas (Eylon and Reif, 1984)—effectively too broad and shallow.

On both AP Physics B and C examinations, the standards for success are low. Indeed a 5, the highest possible score, can be obtained for a score of about 60 percent of the total points available, and a 4 is sometimes given for

scores under 40 percent. The College Board justifies this as a way of allowing students to skip examination questions on topics they may not have covered in class. This justification appears plausible for AP Physics B, with its very broad curriculum; however, it is difficult to see how this reasoning can be applied to AP Physics C, with its much narrower curriculum. Allowing students to skip unfamiliar questions on the examinations can be viewed as a means of permitting instructors who are so inclined to pursue fewer topics in greater depth. The panel members' experiences in preparing students for high-stakes examinations lead us to suspect, however, that few instructors adopt this strategy (this is a question for study) and that the breadth of the examinations is strong motivation for breadth of coverage in instruction.

If the curriculum changes recommended in Chapter 2 were adopted, student mastery of content knowledge could be accurately assessed with improved examinations. At present, the need for the examination to reflect the broad content of the curriculum accurately and consistently, coupled with the low standards discussed above, means that mastery is not being assessed. It is the nature of high-stakes testing that if the test does not assess mastery, teachers will not teach mastery, and most students will therefore not gain it.

Extent to Which Final Assessments in AP Physics Measure or Emphasize Students' Understanding and Application of Concepts

Many of the questions on previous AP physics examinations value technique over conceptual understanding. However, the trend on recent AP physics examinations has definitely been in the direction of increasing the emphasis on conceptual understanding—as it should be. Examples of problems taken from previous AP examinations are presented below. We also note that because the entire final assessment in AP physics is by means of a single written examination, it is not possible to assess the laboratory skills of AP physics students (see Chapter 2).

In general, AP physics examinations require students to do too much in too short a time. Either the time should be lengthened or the amount of material reduced so that students can complete the entire examination. The time issue is important not only because it affects the reliability of the assessment but also because it influences the instructional practices used in preparing students to take the examination. Preparing students to answer many questions in a short amount of time may not be conducive to instilling in them good scientific habits of mind (see Chapter 2).

The following subsections present four sample problems taken from actual AP physics examinations (CEEB, 1994a, 1994b, 1999b). The examples

taken from the 1993 exams are the kind of technical problems of which we have been critical, while those taken from the 1998 exams are good problems that emphasize conceptual understanding.

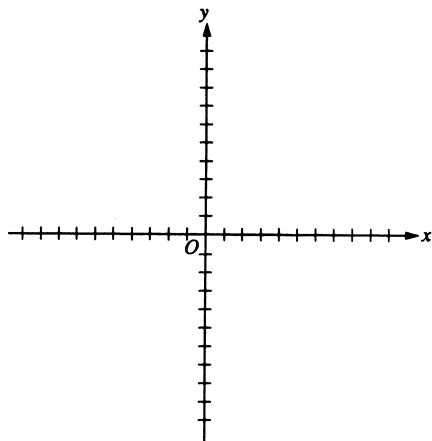
A key issue in these examples is the role of mathematics in good free-response questions. We stress that there are two very different aspects of the use of mathematics in physics problems. First is the translation of parts of physical reality into mathematical models that are usually expressed in the form of equations. Skill in this kind of translation is an important indicator of deep conceptual understanding of physical principles, and its assessment with examination questions is entirely appropriate. Second is the manipulation of the mathematical models to arrive at final results. Skill in this use of mathematics certainly has value but has little to do with the conceptual understanding of physics. Good mathematical examination questions should therefore emphasize skill in the translation of physical reality into mathematics and downplay the subsequent mathematical manipulations. The panel's remarks about the examples given in the following subsections should be viewed in light of this principle.

The reader may ask why we do not also present sample multiple-choice questions. It could be argued that, especially since calculators are not permitted on the multiple-choice portion of the AP examinations, many multiple-choice questions are conceptual in nature. However, the panel believes a reliable assessment of the understanding of students can be made only by requiring students to explain their reasoning and then carefully evaluating those explanations, as discussed in Chapter 2. Since the panel regards the assessment of understanding as the primary goal of examinations, the examples given below are taken from the free-response portion of the examinations.

1993 AP Physics B, Problem 2. This problem (see Figure 3-1) calls for the direct use of the formulas for the electric field and potential of point charges, with a small amount of vector addition required in one part. It is more of a mathematics problem than a physics problem. Although important physical principles play some role (superposition of electric fields and the connection between work and potential energy), the problem could be answered correctly by a student who had memorized the relevant formulas and techniques. The problem is thus a poor tool for assessing conceptual understanding.

1998 AP Physics B, Problem 6. This problem (see Figure 3-2) is similar to the questions asked in the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992). There is nothing to calculate, yet the problem tests extremely important concepts in projectile motion and Newton's laws.

2. A charge $Q_1 = -16 \times 10^{-6}$ coulomb is fixed on the x -axis at +4.0 meters, and a charge $Q_2 = +9 \times 10^{-6}$ coulomb is fixed on the y -axis at +3.0 meters, as shown on the diagram above.
- (a)
- i. Calculate the magnitude of the electric field E_1 at the origin O due to charge Q_1 .
 - ii. Calculate the magnitude of the electric field E_2 at the origin O due to charge Q_2 .
 - iii. On the axes below, draw and label vectors to show the electric fields E_1 and E_2 due to each charge, and also indicate the resultant electric field E at the origin.



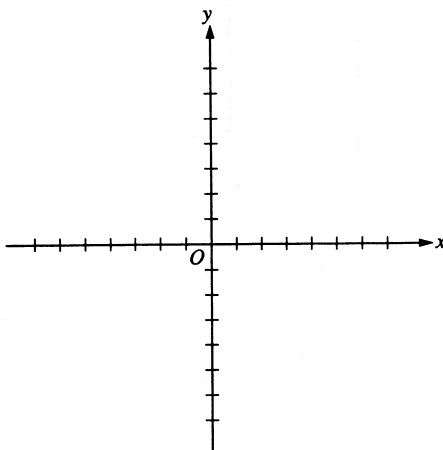
- (b) Calculate the electric potential V at the origin.

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FIGURE 3-1 1993 AP Physics B problem 2

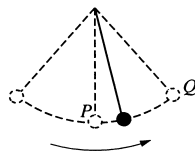
A charge $Q_3 = -4 \times 10^{-6}$ coulomb is brought from a very distant point by an external force and placed at the origin.

- (c) On the axes below, indicate the direction of the force on Q_3 at the origin.



- (d) Calculate the work that had to be done by the external force to bring Q_3 to the origin from the distant point.

FIGURE 3-1 1993 AP Physics B problem 2 (continued)
SOURCE: (CEEB, 1994a).

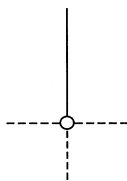


6. (10 points)

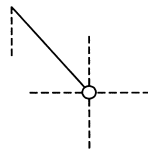
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q . If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P

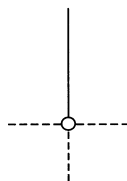


ii. Point Q

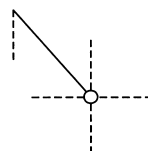


(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q . In each case, briefly describe the motion of the ball after the break.

i. Point P



ii. Point Q



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FIGURE 3-2 1998 AP Physics B problem 6
SOURCE: (CEEB, 1999b)

1993 AP Physics C Mechanics, Problem 2. This problem (see Figure 3-3) is almost entirely a mathematics problem, involving the solution of an elementary differential equation that many AP Physics students would know from memory. The first two parts contain a rudimentary application of Newton's second law.

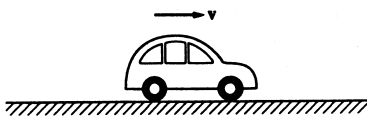
1998 AP Physics C Electricity and Magnetism, Problem 3. This question (see Figure 3-4) is full of important physics. Newton's laws must be used to express the balance between the component of the weight along the incline and the magnetic force. Faraday's law, Lenz's law, and Ohm's law are all necessary in different parts of the question. Although there is a considerable amount of mathematics involved in part (d), part (e) is a good qualitative question that can be answered from different points of view. We stress that mathematics may be well be necessary to answer some good examination questions, but it is essential that the question focus on important physical concepts.

Extent to Which Final Assessments in AP Physics Measure or Emphasize Students' Ability to Apply What They Have Learned to Other Courses and in Other Situations

The AP physics examinations do very little to measure or emphasize students' ability to apply what they have learned to other fields and situations. The exams are strictly limited to narrowly defined physics content. However, the questions posed sometimes ask students to apply the physical principles they know to situations they may not have previously encountered.

Summary of the Panel's Evaluation of the AP Physics Program

- The AP Physics B program is too broad and should be eliminated as a 1-year course.
- The mechanics components of AP Physics B and C should be merged into a single common mechanics component (see Chapter 2).
- AP Physics students in a 1-year program should complete the mechanics program and study at most one other major area of physics. They should be examined separately in each area; standards for success should be high.
- Examinations should emphasize conceptual understanding rather than mathematical manipulation. Recommendations for improving examinations are given in Chapter 2.



Mech. 2. A car of mass m , initially at rest at time $t = 0$, is driven to the right, as shown above, along a straight, horizontal road with the engine causing a constant force F_0 to be applied. While moving, the car encounters a resistance force equal to $-kv$, where v is the velocity of the car and k is a positive constant.

- (a) The dot below represents the center of mass of the car. On this figure, draw and label vectors to represent all the forces acting on the car as it moves with a velocity v to the right.

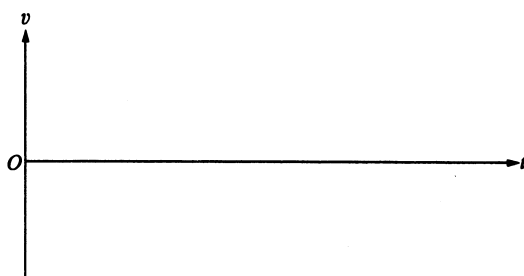


- (b) Determine the horizontal acceleration of the car in terms of k , v , F_0 , and m .
- (c) Derive the equation expressing the velocity of the car as a function of time t in terms of k , F_0 , and m .

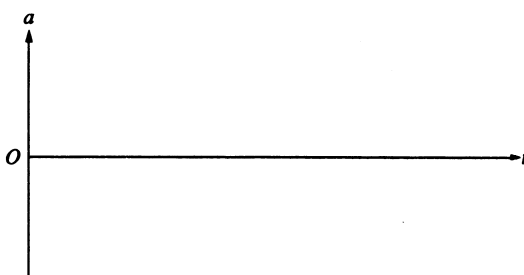
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FIGURE 3-3 1993 AP Physics C Mechanics, problem 2

- (d) On the axes below, sketch a graph of the car's velocity v as a function of time t . Label important values on the vertical axis.



- (e) On the axes below, sketch a graph of the car's acceleration a as a function of time t . Label important values on the vertical axis.



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FIGURE 3-3 1993 AP Physics C Mechanics, problem 2 (continued)
SOURCE: (CEEB, 1994b)

- Accomplishing the necessary improvements will require a willingness to alter radically the philosophy of AP Physics examinations. During the transition, the meaning of examination scores will change, so that they may not be consistent with scores on earlier exams. It will therefore be necessary to give up consistency in the statistics of examination scores from year to year as the transition occurs.

THE IB PHYSICS PROGRAM

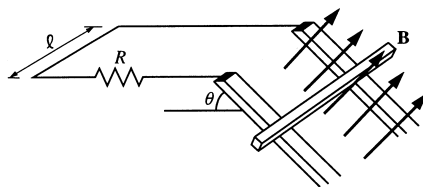
In this section, we respond directly to the questions under the panel's charge (see appendix) related to curriculum and assessment for the IB physics program. By IB physics we mean the Higher Level (HL) IB Physics course, a 2-year course. In contrast to AP physics, the curriculum for IB physics is spelled out quite thoroughly by the International Baccalaureate Organisation (IBO), down to the number of hours to be spent teaching each rather small division of subject matter.¹⁴ For example, 1 hour of teaching time is allocated to the introduction of vectors and scalars, the addition of coplanar vectors by graphical means, and multiplication of vectors by scalars (IBO, 1996, p. 22). In all phases of the course, students are required to spend approximately 25 percent of their time following an internally assessed scheme of practical/investigative work (106).

Schools pay an annual fee to the IBO in order to offer IB courses, and the IBO vigorously enforces its detailed standards for each of its courses offered by a school through periodic inspections and evaluations. IB credit is available only to students who have both completed the IB course and received an acceptable score on the final IB assessment. Again, this practice contrasts sharply with the AP program, in which any student who pays the examination fee can take an AP examination in any subject.

Degree to Which the Factual Base of Information Provided by the IB Curriculum and Related Laboratory Experiences Is Adequate for Advanced High School Study in Physics

There is no question that the factual base of information provided by the IB physics curriculum and related laboratory experiences is fully adequate for a good advanced program. The factual base for IB physics is

¹⁴The careful specification of the IB physics curriculum, however, should not be construed as requiring either a particular order of instruction or definite teaching times. The new IB Physics Guide for first examinations in 2003 makes clear that this detailed information is intended only as a guide (IBO, 2001, p. 4).



E & M. 3. A conducting bar of mass m is placed on two long conducting rails a distance l apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m , l , θ , B , R , and g .

- Determine the current in the circuit when the bar has reached a constant final speed.
- Determine the constant final speed of the bar.
- Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.
- Express the speed of the bar as a function of time t from the time it is released at $t = 0$.
- Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

FIGURE 3-4 1998 AP Physics C Electricity/Magnetism, problem 3
SOURCE: (CEEB, 1999b)

approximately the same as that for AP Physics B, except that the time allotted is a much more reasonable 2 years.

As in the case of AP physics, the IB program does not mandate the completion of specific laboratory exercises. However, IB physics students must spend 25 percent of their time doing practical/investigative work “over a prolonged period”¹⁵ (IBO, 1996, p. 106). This time need not be devoted entirely to conventional laboratory exercises; computer simulation studies would also be acceptable, for example. However, because teachers of advanced physics courses need to be able to adjust their teaching objectives and techniques in response to their continuing evaluation of the understanding of their students (see Chapter 4), the panel believes the 25 percent requirement is too inflexible.

Extent to Which the IB Curriculum and Assessments Balance Breadth of Coverage with In-Depth Study of Important Topics in Physics

Because the IB physics program spans a 2-year period, it does not suffer from the same problems as AP Physics B. The material can reasonably be covered in considerable depth in a 2-year course.

IB physics contains no calculus and as a result cannot pursue the detailed study of electric and magnetic fields found in AP Physics C. The panel believes that the mathematical study of electricity and magnetism should be an available option in the IB program that could be selected by an instructor with mathematically advanced students.¹⁶

Degree to Which IB Physics Courses Are Organized Around Key Concepts to Promote Conceptual Understanding

As noted above, the panel believes Newtonian mechanics should provide the conceptual foundation for all advanced physics programs. IB physics contains a strong Newtonian mechanics component. In addition, there are already a number of well-defined optional topics that can be selected by individual IB instructors, as recommended in Chapter 2.

¹⁵This practical work is internally assessed and must last for at least two-thirds of the time the course is taught.

¹⁶At one time, the IB program contained an Electricity and Magnetism option that required calculus. The option was dropped because it was not popular. This does not prevent IB teachers from using calculus with mathematically advanced students; however, current IB examinations do not contain questions that require the use of calculus.

The mechanics component of IB physics currently includes rotational dynamics, as recommended in Chapter 2. However, the new IB physics syllabus (IBO, 2001), which applies to any student starting the 2-year program in August 2001 or later, does not include this topic.

Degree to Which the IB Physics Curriculum and Related Laboratory Experiences Provide Opportunities for Students to Apply Their Knowledge to a Range of Problems in a Variety of Contexts

The IB curriculum provides ample material for problem solving. Indeed, as noted earlier, problem solving is an indispensable part of any advanced physics course. As with the AP program, however, the range and variety of contexts of problems can vary substantially among specific implementations at different high schools. Therefore, the opportunities advanced students have to apply their knowledge to problems in a variety of contexts depends upon the particular IB physics program in which they are enrolled.

Extent to Which the IB Physics Curriculum and Related Laboratory Experiences Encourage Students and Teachers to Make Connections Among the Various Disciplines in Science and Mathematics

As noted earlier, the connection between physics and mathematics is very strong, and the IB physics course calls upon students to use substantial mathematical skills. However, the IB physics course does not use calculus.

Some of the IB options, such as Biomedical Physics and Historical Physics, connect physics with other disciplines. In addition, all students are required to carry out a Group 4 project in which students are encouraged to combine concepts from different disciplines in a collaborative, investigative experience (IBO, 2001, pp. 27–32). There is great flexibility in the choice of projects and the types of work required; it is therefore difficult to evaluate the educational impact of the Group 4 project requirement.

Extent to Which Final Assessments in IB Physics Measure or Emphasize Students' Mastery of Content Knowledge

The IB HL Physics final assessment is much more extensive than its AP counterpart. There are three written papers that together account for 76 percent of the student's final IB score (given on a 1–7 scale): a 1-hour sec-

tion consisting of 40 multiple-choice questions; a $2\frac{1}{4}$ -hour free-response section containing one data-based question, several short-answer questions, and one extended-response question; and a $1\frac{1}{4}$ -hour free-response section on the two optional topics studied (IBO, 2001, p. 14). Students have minimal freedom in selecting which questions to answer on the second paper. In contrast, students are required to answer all questions on the AP examinations.

The pace of the IB examinations is much more leisurely than that of the AP examinations, which require a student to complete 70 multiple-choice questions in 90 minutes and then six to eight free-response problems in a further 90 minutes. Of course, a precise comparison of the time pressure involved in different examinations requires a careful comparison of the questions asked on each exam. Nevertheless, the panel reviewed a considerable number of examinations in each program and is confident in its assessment that IB examinations create far less time pressure than AP examinations.

The IB examination also allows a 10-minute reading time for written papers. During this time, students can review the paper to decide what questions to answer but cannot do any written work. The exam time starts after the reading time. The panel applauds the longer time allowed in the IB case; as discussed in Chapter 2, we firmly believe in giving students the time they need to think.

The questions on the IB physics examinations are generally of a more conceptual nature than those on the AP physics examinations (as discussed below), another feature the panel applauds. Nevertheless, the written IB physics examinations suffer from many of the same problems discussed in Chapter 2:

- Too many questions have multiple parts that lead students through the solution.
- Insufficient attention is paid to reasoning in the scoring rubrics. Too rarely is credit deducted for incorrect statements.
- Rigid scoring rubrics need to be replaced by an overall evaluation of the totality of each student's response.
- The standards for success on IB examinations are comparable to those on AP examinations—far too low, in the opinion of the panel.

The remaining 24 percent of each student's IB score comes from an internal assessment made by the IB teacher of the student's laboratory work. To make this assessment, the teacher applies a set of stringent criteria that are carefully spelled out by the IBO (2001, pp 15–26). The IBO requires sample papers from schools to verify that these criteria are being applied correctly. Thus the IB final examination provides for an assessment of laboratory skills—something entirely lacking in the AP program. However, the

larger question remains of whether the laboratory investigations of IB students are really meaningful educational experiences. If they are not, they are not worth assessing.

Extent to Which Assessments in IB Physics Measure or Emphasize Students' Understanding and Application of Concepts

As mentioned in the preceding section, IB physics examinations generally place more emphasis on conceptual understanding than their AP counterparts, as illustrated by the two examples given below. However, this emphasis is still insufficient to enable a reliable assessment of such understanding for the reasons discussed earlier.

Figure 3-5 is question #A2 from paper 2 of the November 1999 IB Physics HL examination. There is nothing to calculate, yet the question tests students' understanding of Newton's second law in a variety of settings. It is an excellent conceptual question.

Figure 3-6 is question #B3 from the same examination paper. Part (a) of the problem begins with two "plug-in" uses of the formulas for projectile motion, but then continues with a graph in which students need to demonstrate their understanding of the oscillatory nature of the motion of the ball. The problem then continues with two short essay parts in which students have to explain physical principles. Part (b) is largely an exercise in the use of simple formulas, but part (c) contains another short essay question that tests students' understanding of angular momentum conservation.

Extent to Which Final Assessments in IB Physics Measure or Emphasize Students' Ability to Apply What They Have Learned to Other Courses and in Other Situations

The final assessments in IB physics do little to measure or emphasize students' ability to apply what they have learned to other fields and situations. Yet they perhaps do somewhat more than the AP examinations in this regard because of the inclusion of optional units that are interdisciplinary in nature.

Summary of the Panel's Evaluation of the IB Physics Program

- The IB physics program is a good 2-year course. With respect to the pace at which it addresses topics, covering largely the same material as AP Physics B, it may be ideal.

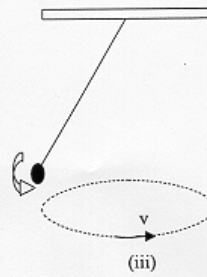
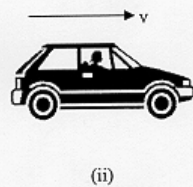
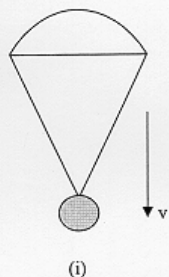
- 5 -

N99/430/H(2)

A2. This question is about forces and motion.

The diagrams below show three different situations where an object is travelling at constant speed.

- (i) a mass attached to a parachute descending at constant velocity.
- (ii) a car travelling forward at constant velocity.
- (iii) a pendulum bob moving in a horizontal circle at constant speed.



- (a) On the diagrams add labelled arrows to represent the main forces acting on the mass, the car and the pendulum bob. [6]
- (b) Discuss how the forces acting in each case can result in the speed being constant. [4]

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Turn over

FIGURE 3-5 November 1999 IB Physics HL, paper 2, question A2.
SOURCE: (IBO, 1999a)

B3. This question is about oscillations and momentum.

(a) A ball is dropped from rest from a height of 20 m onto a hard surface where it makes an elastic collision. If frictional losses are very small, it returns to its original height and continues to bounce up and down.

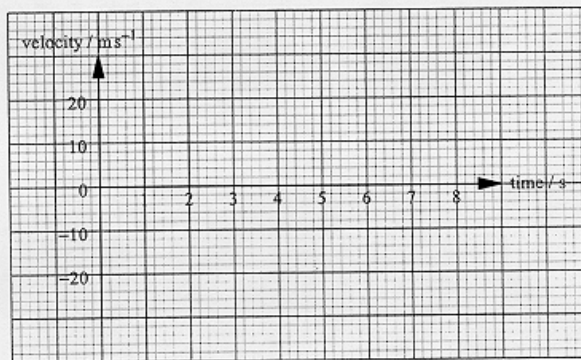
(i) Show that the time taken for the ball to reach the ground from its starting position is 2 s. [2]

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(ii) Show that the speed of the ball just before it hits the ground is 20 m s⁻¹. [2]

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(iii) Use the axes below to sketch a graph of how the velocity of the ball varies with time during several bounces. [4]



(This question is continued on the following page)

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3

(Question B3 continued)

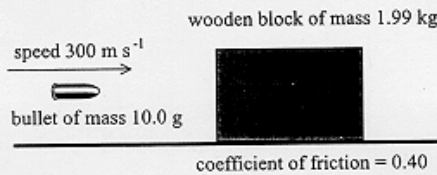
- (iv) Explain how the principle of the conservation of linear momentum applies to the situation of the ball falling towards the floor. [2]

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- (v) Is this bouncing motion an example of simple harmonic motion? Justify your answer. [3]

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- (b) The diagram below shows a wooden block of mass 1.99 kg resting on a flat surface. It is about to be struck by a bullet of mass 10.0 g moving with a speed of 300 m s^{-1} . The coefficient of friction between the block and the surface is 0.40.



The bullet becomes embedded in the block.

- (i) Calculate the speed with which the block moves off after being struck by the bullet. [2]

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(This question continues on the following page)

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3 (continued)

(Question B3 continued)

- (ii) Calculate the distance that the block moves along the table before coming to rest. [5]

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- (c) A large horizontal turntable has a moment of inertia of $5 \times 10^{-3} \text{ kg m}^2$. It is free to rotate about its centre. It is doing so at 30 revolutions per minute, when a 50 g mass falls vertically onto it. The mass sticks to the turntable and the combined system now rotates at a constant 25 revolutions per minute.

- (i) Calculate the original angular momentum. [3]

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- (ii) Explain why the turntable slows down when the mass attaches to it. [2]

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(This question continues on the following page)

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3 (continued)

- 20 -

N99/430/H(2)

(Question B3 continued)

(iii) Calculate the distance of the 50 g mass from the centre of the turntable.

[5]

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889-227

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3 (continued)
SOURCE: (IBO, 1999a)

- The IB curriculum's fixed minimum allocations of time to activities such as "practical investigative work" and the Group 4 project are somewhat troubling; it is far from clear that all the mandated activities are educationally worthwhile. Also, such fixed time allocations are in conflict with the teacher's need to adjust instructional strategy in response to a continually changing diagnosis of student understanding (see Chapter 4).
- The IB Physics course contains no calculus and therefore cannot delve as deeply as AP Physics C into electromagnetic theory.
- The IB physics examinations are more conceptually based than the AP physics examinations and give students sufficient time to think but suffer from many of the same faults of construction as the AP exams.
- Unlike the AP program, the IB program can assess laboratory skills by means of the internal assessment process.

4

Teaching and Learning in Advanced Physics Programs

In the preceding chapters, advanced high school physics programs are discussed as if they can be separated from the particular teachers and students involved. Adopting this point of view greatly simplifies the discussion and makes it possible to draw some important conclusions. Nevertheless, the panel is convinced that the success of a given advanced high school physics program depends much more on the teachers and students than on the curriculum or other general program characteristics. We stress that in truth there is no such thing as *the* Advanced Placement (AP) physics program or *the* International Baccalaureate (IB) physics program. Rather, as noted earlier, the implementation of these programs varies widely from school to school and teacher to teacher, and these variations often have a much greater impact on the education of the students than the choice of which program to implement. In this chapter, we examine the characteristics of teachers and students that give rise to these critical variations in the implementations of AP and IB physics. Based on this examination, we offer several recommendations for improving the overall quality of advanced high school physics instruction.

THE TEACHERS OF AP AND IB PHYSICS

In the opinion of the panel, the most important factors in determining the quality of advanced physics instruction in high school are the talent and preparation of the teacher.¹⁷ To achieve widespread high-quality advanced physics instruction, it is necessary to provide for both recruitment of highly qualified college students into the teaching profession and strong, substan-

¹⁷The importance of the teacher is supported by objective evidence. When the Force Concept Inventory examination was given to the classes of teachers with poor preparation in physics and also to the teachers themselves, it was found that students' scores never exceeded the score of their teacher.

tive preservice and inservice professional development of physics teachers.¹⁸

Competitiveness of Salaries of Physics Teachers

While both beginning and average teachers' salaries have improved relative to inflation since the 1980s (Neuschatz and McFarling, 1999), the present competition for technical expertise makes salary an important factor in attracting new teachers to the profession. It is difficult to see how enough well-qualified college students can be attracted to the teaching of advanced physics courses when a similar amount of training would allow them to earn much higher salaries in other positions.

Low salaries not only make it difficult to attract people to the teaching profession but also lead to a general lack of respect for teachers. "If you could do something else, you wouldn't be here" is a far too common conclusion reached by students, parents, and others about the teachers they depend on for education.

Role of AP and IB Organizations in the Training and Credentialing of Teachers

At present, neither the AP nor the IB program requires any special credentials or teacher preparation for teaching its courses other than what is required by the school and the state in which the school is located. The IB program does require teachers to be trained in IB procedures when a school first joins the IB program; this initial training also includes a content work-

¹⁸In May 1999, the Council of the American Physical Society adopted the following statement:

AIP-Member Society Statement on the Education of Future Teachers: The scientific societies listed below urge the physics community, specifically physical science and engineering departments and their faculty members, to take an active role in improving the pre-service training of K-12 physics/science teachers. Improving teacher training involves building cooperative working relationships between physicists in universities and colleges and the individuals and groups involved in teaching physics to K-12 students. Strengthening the science education of future teachers addresses the pressing national need for improving K-12 physics education and recognizes that these teachers play a critical education role as the first and often-times last physics teacher for most students. While this responsibility can be manifested in many ways, research indicates that effective pre-service teacher education involves hands-on, laboratory-based learning. Good science and mathematics education will help create a scientifically literate public, capable of making informed decisions on public policy involving scientific matters. A strong K-12 physics education is also the first step in producing the next generation of researchers, innovators, and technical workers (<http://www.aps.org/statements/99.1.html> [4/17/2002]).

shop for teachers. In addition, the IB program provides numerous optional content workshops for IB physics teachers at locations around the world.

A number of institutions offer 1- or 2-day AP workshops or summer institutes, but these are not required of teachers offering AP courses. The panel suggests that the College Board and the International Baccalaureate Organisation (IBO) consider whether requiring such workshops or introducing some form of mandatory or optional credentialing would improve the quality of preparation of teachers of their programs.

A recent American Institute of Physics survey (Neuschatz and McFarling, 1999) notes that about one-third of high school physics teachers have a degree in physics or physics education, and an additional one-sixth have a minor in physics. Almost all the rest have degrees either in another science or in mathematics. Many report being inadequately trained to use computers in the laboratory and the classroom, and only half report taking part in any physics workshop, meeting, or course during the year preceding the survey. The panel believes such training deficiencies are a major cause of unsuccessful outcomes in advanced physics teaching.

Involvement of College and University Physics and Engineering Faculty in the Training of Teachers of Advanced High School Physics

The *National Science Education Standards* (National Research Council [NRC], 1996) contain detailed standards for the professional development of science teachers. The panel urges the cooperation of the entire physics community in the recruitment and training of physics teachers who meet those standards. In particular, we join the American Institute of Physics, the American Physical Society, the American Association of Physics Teachers, and other physics organizations in calling on college physics and engineering faculty to take an active role in the training of teachers for advanced high school physics programs.¹⁹

The panel concurs with the opinion of Robert Watson, director of the Division of Undergraduate Education at the National Science Foundation, that if science departments in colleges and universities were more hospitable to students who wanted to become teachers, not only would those students be better prepared to go into teaching but a much stronger cadre of students would be attracted to teaching (NRC, 1997a, p. 4). Physics departments need to treat high school physics teaching as an honorable specialization for an undergraduate physics major and provide both undergraduate

¹⁹See the December 1999 *Statement on the Education of Future Teachers* at www.AIP.org.

and graduate courses of study aimed at the preparation and continued professional development of skilled physics teachers.

Physics departments should pose the prospect of high school teaching as an option in advising students, perhaps in conjunction with a local physics teacher who could provide perspective on such a career choice. Physics majors specializing in education should take the same foundational courses as conventional physics majors, replacing some elective or specialized coursework with courses of similar rigor that probe in depth the problems of learning and teaching physics. Such courses should include the use of traditional techniques, as well as modern teaching techniques based on research on physics education. Recognizing that a substantial fraction of all undergraduate physics majors will end up instructing others in some fashion at some time in their careers, a course in teaching and learning would be a useful addition to the physics major in general, although the details of such a course would vary. The panel notes that some programs of this type are already in operation (see, for example, Roelofs, 1997).

Preparation Needed to Teach Advanced Physics Courses Effectively

There is no doubt that to teach advanced physics effectively a strong background in physics content is absolutely essential. Teachers who do not understand the subject themselves cannot possibly develop deep conceptual understanding of physical principles in their students.

However, a thorough understanding of the subject matter is not sufficient. A teacher must also be skilled in the specialized pedagogy of physics. Physics teachers need to be trained to understand their students' view of the physical world (which is often radically different from that of physicists) and adjust their teaching techniques accordingly (as discussed below).

EFFECTIVE TEACHING IN ADVANCED PHYSICS PROGRAMS

Another reason for the varying degrees of success among teachers is that different teachers teach in different ways. A great deal of research has been done to identify the most and least effective teaching practices for educating students of science. In this section, we summarize the main results of that research from the point of view of advanced physics instruction.

Findings of Research on *How People Learn*

A number of summaries of the implications of recent research on learning for the teaching of science have been prepared. The panel notes and

endorses the NRC (2000) report *How People Learn: Brain, Mind, Experience, and School: Expanded Edition*. Adapting and elaborating these findings specifically for the study of physics leads to the following implications for effective instruction.

1. Teachers must draw out and work with students' current understandings, including those students bring with them to the course and those they develop as the course progresses.

There is a robust consensus in education research, including a substantial body of work specific to introductory physics (Champagne, Gunstone, and Klopfer, 1985; Clement, 1982; Hake, 1998; Hestenes, Wells, and Swackhamer, 1992; McDermott and Redish, 1999), that to be effective, instruction must elicit, engage, and respond substantively to student understandings. There are now a number of examples of curricula and materials designed to support productive interaction with student understandings (as discussed later in this chapter), and there is evidence that these approaches can achieve progress in understanding not possible for most students with traditional methods.

2. Teachers must address students' metacognitive skills, habits, and epistemologies.

Students need to understand not only the concepts of physics but also the nature of knowledge and learning (Halloun, 1998; Hammer, 1995; Hewson, 1985; McDermott, 1991; Redish, Steinberg, and Saul, 1998; Reif and Larkin, 1991; White and Frederiksen, 1998). Many students arrive at physics courses, including advanced courses, expecting to learn by memorizing formulas disconnected from each other, as well as from the students' experiences of the physical world. Effective instruction challenges these expectations, helping students come to see physics learning as a matter of applying and refining their current understanding. Students must learn to identify and examine assumptions hidden in their reasoning; to monitor the quality and consistency of their understanding; to formulate, implement, critique, and refine models of physical phenomena; and to make use of a spectrum of appropriate representational tools. By the end of an advanced course, students should have developed a rich sense of the coherent, principled structure of physics and be both able and inclined to apply those principles in unfamiliar situations. In short, effective instruction should work toward the objectives identified in Chapter 2.

Many teachers start off well by explaining to their students that success in studying physics depends on learning and applying general principles, rather than on memorizing many unrelated facts and formulas. Talk, however, is cheap. Too many teachers follow up these commendable words by

evaluating their students on the basis of their skill in solving problems that are handled most efficiently by just such memorization. Teachers must design the assessments in their courses to make the statement that “success depends on learning and applying general principles” a reality.

3. Effective teachers are sophisticated diagnosticians of student knowledge, reasoning, and participation.

How teachers respond to student thinking depends critically on what they perceive in that thinking, on what they interpret to be the strengths and weaknesses of the student’s understanding and approach.²⁰ Effective teachers continually gather information to support this ongoing assessment from several different sources: written work on assignments, tests and quizzes, classroom discussions, and contact with students outside the classroom. They ask students to explain their reasoning throughout their work. Upon gaining new insights into student understanding, effective teachers adapt their instructional strategies and objectives. For this reason, teachers must be trained both to make accurate diagnoses of student thinking and to devise effective responses to that thinking (as discussed earlier).

4. Teachers must teach a smaller number of topics in greater depth, providing many examples in which the same concept is at work.

This is a common refrain in findings from education research, often expressed in the slogan “less is more.” In part, this precept is an implication of the previous two: drawing out and working with student understandings and addressing metacognitive skills and habits all take time, and this necessitates a reduction in the breadth of coverage. Education research also yields the robust finding that coming to understand a concept requires multiple encounters in multiple contexts. This finding is reflected across innovations in physics curricula (see the discussion later in this chapter).

A related consideration is that effective teaching requires limiting class sizes to a reasonable number. Drawing out, evaluating, and working to improve student understandings is a highly individualized process that is nearly impossible to perform adequately in oversized classes.

These admonitions from education research are not controversial, but their generality may allow multiple, superficial, and possibly conflicting in-

²⁰For an extended discussion and example of diagnosis in a high school physics class, see Hammer (1997). For an account of facets-based diagnosis, see Minstrell (2000). Diagnoser, a software tool designed to support facets-based diagnosis of student thinking, is available at <http://depts.washington.edu/huntlab/diagnoser> [4/23/02].

terpretations. If these points are to be meaningful, it is essential that they be discussed with respect to specific instances of learning and instruction (examples include Minstrell, 1989; Hammer, 1997; Roth and Lucas, 1997; and van Zee and Minstrell, 1997).

Special Considerations in Advanced Physics Instruction

The panel acknowledges that there are students who are successful at learning under almost any circumstances, that these students often appear in advanced courses, and that for them the implications of the previous section may not be as critical. However, such students do not appear to constitute the majority of those enrolled in advanced courses. Moreover, even the best students would benefit from the recommendations of the research discussed above.

With these considerations in mind, the panel's first concern regarding advanced courses is that the breadth of the curriculum often leaves very little time to do anything but introduce new subject matter. Therefore, a serious attempt to improve instructional practices will require giving up coverage of some material. The panel's recommendations for accomplishing this are presented in Chapter 2.

The panel's second concern is that the emphasis in advanced courses on solving typical textbook problems as opposed to conceptual discussion and debate tends to encourage rather than challenge student perceptions that physics knowledge comprises disconnected factual units rather than a principled system of ideas. Although skill in problem solving is an important objective of any advanced physics program, conceptual understanding must be the objective of highest priority.

Extent to Which the AP and IB Curricula and Assessments Encourage Teachers to Use a Variety of Teaching Techniques

As described in Chapter 3, the College Board leaves the way in which AP physics is taught entirely to the particular implementation of AP physics in each school. There are no requirements that must be met before students can take the AP examinations. Although the College Board does offer advice to teachers in various publications, it is entirely up to the particular school whether to accept or reject that advice. The only means the College Board has of encouraging teachers to use a variety of techniques is through the construction of the examinations. Recent examinations have tended to emphasize conceptual understanding and real-world situations to a greater degree than earlier examinations. To the extent that a variety of teaching tech-

niques is necessary to prepare students to answer these kinds of questions, the use of such varying techniques is encouraged.

In contrast, the IBO spells out in great detail the time to be spent doing different kinds of activities in IB physics courses. For example, 25 percent of instructional time is to be spent by students pursuing a program of “practical work” (see Chapter 3). Moreover, a great deal of written material is available to IB teachers containing detailed suggestions for carrying out these activities. Thus the IBO most definitely encourages the use of a variety of teaching techniques and in fact goes a long way toward mandating the use of such a variety.

Whether the use of that variety is effective in the IB program, however, is entirely another matter. As discussed earlier, teachers need to be free to adjust their teaching techniques and objectives as they continually diagnose the state of understanding of their students. The IB program’s prescriptions of time to be spent in various activities may deprive teachers of the flexibility they need. The panel is skeptical that such inflexible prescriptions are appropriate for advanced physics instruction.

The panel has been informed through personal testimony and anecdotal evidence that some experienced IB physics teachers do not feel constrained to follow these time prescriptions. The panel considers the full use of whatever flexibility is available to be entirely appropriate.

Differences Between High School Physics Instruction in the United States and Other Countries

In light of the poor performance of U.S. students on the physics portion of the Third International Mathematics and Science Study (TIMSS) as compared with students from other developed countries (see National Center for Education Statistics, 1998), certain characteristics of the U.S. physics education program need serious reconsideration and further study. To be clear, the panel is not endorsing TIMSS as the way to measure success in physics education; rather, we believe the lower scores of American students are a good reason to explore what can be learned from the methods of physics instruction used in other TIMSS countries.

Perhaps the most obvious difference between physics instruction in the United States and other countries is the number of secondary school years devoted to physics study. In most TIMSS countries, students develop their physics knowledge over a period of many years, rather than the traditional 1 year commonly offered in the United States. The system used by other countries appears to be more consistent with the findings of education research that coming to understand a concept requires multiple encounters in multiple contexts.

One possibility for American programs to consider is moving the single year to a different position in the traditional “layer-cake sequence.” Doing so might change the mathematical level at which physics is taught or might involve students at a different stage of cognitive development. It might also facilitate the use of physics in interdisciplinary high school science classes such as those encompassing biology and physics.

Another alternative is to offer physics along with other scientific disciplines in an integrated or coordinated course for the first 2 years of high school and then offer further physics study in the junior or senior year at an advanced level. This approach is similar to that of science programs in most comparison countries. Additional years of integrated science courses in the third and fourth high school years is another possibility. Given the scarcity of comparison data on these sequences and the fact that many schools in the United States are making the transition to integrated courses as a result of exciting new curricular offerings, this is an excellent time to examine these issues.

A second significant area of difference between physics instruction in the United States and other TIMSS countries lies in the recruiting, training, professional development, and status of physics teachers. The salary situation for American secondary school physics teachers is particularly troubling (as noted earlier). First, the difference in salary between positions attainable by physics majors (e.g., computer programmer, laboratory technician) and the position of beginning teacher is much greater in the United States than in most comparison countries. Second, the comparison with professions unrelated to physics is no better. In Japan, for example, secondary school teachers are in the top 20 percent of the professional salary scale; in the United States, they are in the bottom 20 percent. Salary issues related to recruitment and retention need to be addressed for the U.S. physics teaching profession before we find ourselves with far too few qualified teachers or mentors.

A third area of difference is reflected in the fact that some of the TIMSS content involves topics not commonly covered in U.S. physics courses. One example, thermodynamics, not only is poorly understood by many physics teachers and therefore avoided but also is often left to chemistry teachers as a part of their curriculum. Although the United States is generally perceived to teach more science topics in less depth than is the case in other countries, physics topics beyond mechanics and electricity and magnetism are often mentioned in a highly perfunctory fashion. U.S. students may well have no experience with these topics, especially on exams. Other examples are the lack of emphasis on statistics and statistical analysis and the lower factual content in U.S. textbooks compared with many European high school texts. More data are needed to determine whether these and other mismatches put U.S. students at a disadvantage.

U.S. students also appear to spend more class time doing laboratory work and to do more independent work than their counterparts in other countries. Although many believe these uses of student time encourage the development of creative, bold, and imaginative physicists, the time spent in the laboratory may diminish that devoted to other physics class activities, such as problem solving, which may in turn affect test scores.²¹

Finally, unlike the United States, many comparison countries have extensive evaluation and assessment programs. Since most foreign countries have national educational assessments, their evaluation processes may be more efficient and meaningful in such disciplines as physics. Some programs have been in place for at least 100 years, involve highly trained teachers as external graders, and publish school scores publicly. The availability of long-term student assessment data may be an important factor leading to the educational success of those programs.

THE STUDENTS OF AP AND IB PHYSICS

This section examines how the nature of the student body affects educational outcomes in advanced physics instruction. The students who take AP and IB physics courses come from a wide variety of academic, cultural, and socioeconomic backgrounds. This diversity can only increase as both programs continue to expand in size. An effective implementation of AP or IB physics must take into account the background of the students enrolled in that particular implementation.

The Problem of Widely Varying Levels of Academic Preparation and Ability

Variations in abilities and preparation levels make teaching an advanced physics program more difficult for both teacher and students. When the ability or preparation of some students is far below the expected prerequisite level for advanced study, the teacher is faced with the unenviable choice of either decreasing the extent or depth of content coverage to accommodate those poorly prepared students, thereby failing to meet the needs of the students who are adequately prepared; or teaching the course at the level appropriate for the adequately prepared students, thereby failing to meet the needs of those who are poorly prepared.

The panel wishes to emphasize that preparation must include more than background knowledge and related skills. It must also include the develop-

²¹This observation is offered only as a possible contributing factor to the low TIMSS scores of American students. Naturally, we are far more interested in developing creative scientists than in catching up on test scores.

ment of mature work habits. Students who do not complete their homework or are generally unwilling or unable to put forth sustained high levels of effort are unlikely to succeed in advanced physics study in high school and may have effects on other students' learning that cannot be ignored.

It is not possible to avoid inappropriate placement situations entirely—nor would doing so be desirable. Students who want to try a difficult course because they are genuinely interested should be encouraged to do so, provided they are made fully aware of the commitment of time and effort they are about to make. For some of these students, a well-taught and challenging advanced course in physics could spark learning and interest that had previously gone unrecognized. On the other hand, seriously underqualified students should be discouraged from taking advanced physics. Doing poorly in a course for which a student is not prepared often discourages the student from further study in the field and certainly will not enhance his or her application to college.

These are complex issues with no easy solutions, and we recognize that not everyone will share our views. The panel recommends discretion in the assignment of students to advanced courses,²² so that the teacher is able to maintain the integrity of the course as an advanced treatment of the concepts being covered. For example, in solving projectile motion problems, a comprehensive treatment is commonly not accessible to some fraction of the class simply because they do not know how to solve quadratic equations. The panel believes appropriate members of each school's staff should be involved in decisions about admitting individual students to the school's advanced physics program. Of course, the school staff should consult with students and their parents and consider their views carefully in the deliberations, as appropriate. School personnel, students, and parents should be clear about what constitutes adequate preparation for an advanced physics program. Such preparation might include background knowledge and related skills, such as mature work habits.

At first glance, it may appear most fair to deny admission to underprepared students. However, many students lack the necessary preparation because of limited educational opportunities beyond their control. Moreover, as noted above, some of these students may experience an academic awakening when provided with such opportunities. The panel believes it is the job of the school staff to identify those underprepared students who are likely candidates for such experiences and admit them to the advanced physics program regardless of prerequisites. Doing so may require extensive interviews with

²²Normally, this discretion is exercised by the school administration. The standards set by the administration should reflect the best interests of the students in that particular school. The panel believes failure to exercise such discretion can make it impossible to run a successful advanced physics program.

the student, the student's parents and teachers, and others who know the student well. Making these judgments is not easy, but we believe it is within the capability of a skilled educational staff.

Ultimately, the way to expand access to advanced physics is to reform the education system so that all students will be able to experience a rigorous academic program that will allow them to study advanced physics in their late high school years if they choose to do so.

Role Played by the Culture of the American High School

Students do not take advanced physics in a vacuum. They are constantly interacting with the surrounding high school environment, which places substantial demands on them physically, intellectually, socially, and morally. Since the study of advanced physics is itself a demanding pursuit, there is a constant struggle between the advanced physics program and other activities for the attention of students. To be successful, an advanced physics program must adapt itself to the particular high school environment and find a way to use whatever time students can devote to the program to best educational advantage.

Competing activities that place demands on the time of advanced physics students include part-time employment; athletics; community service; music and drama; college visits; television and movies; computer activities, including Web surfing; family vacations; and social events. Much of the pressure to engage in these activities comes from colleges and universities. In a desire to enhance their college applications, students often undertake an enormous variety of activities that leave them too little time for their studies. Pulled in so many directions at the same time, these students have a low attention span, both in class and in doing their homework.

It must also be recognized that English is not always the native language of advanced physics students. Since the concepts of advanced physics are new and difficult for many students, a poor command of English can cause serious problems for those who are otherwise quite well prepared for the course. Even for native English speakers, the specialized use of common words such as *momentum* or *work* often leads to confusion. Those effects are exacerbated among students for whom English is a second language. In addition, cultural influences can affect how students think about science: reasoning by analogy or by strict linear logic; memorization of specific correct responses or generalization; problem solving by induction or by deduction; or needing to learn through hands-on apprenticeship to gain one aspect of a skill before moving on to the next step (Kolodny, 1991). Cultural prohibitions permeate some societies; for example, values that discourage assertiveness, outspokenness, and competitiveness in some cultures result

in behavior that can be interpreted as being indifferent, having nothing to say, or being unable to act decisively (Hoy, 1993; NRC, 1997b, p. 59). The problems engendered by these cultural differences are often beyond the ability of teachers of advanced courses to handle on their own. In many such cases, support from other members of the school staff is essential.

Finally, we note that advanced programs should use the resources of the community to maximum advantage. In many cases, local corporations are willing to make substantial contributions of equipment for the use of advanced physics programs. They also often run special programs and competitions that are highly stimulating to advanced students. Government laboratories and colleges can have a large positive impact on advanced programs as well by giving students the opportunity to meet practicing scientists and explore laboratories in which research at the forefront of physics is taking place. Teachers of advanced courses should avail themselves of these special opportunities in their communities.

ALTERNATIVE CURRICULAR MATERIALS FOR ADVANCED PHYSICS INSTRUCTION

Many excellent advanced physics courses can be developed using traditional physics texts because a skilled teacher can modify the material to incorporate interactive engagement techniques (Hake, 1998) that enhance student learning. It would be better, however, to have curricular materials that directly support interactive engagement. This section describes several examples of such materials to demonstrate the variety of alternative resources available and to provide some concrete examples of what is meant by interactive engagement. The panel makes no claim of completeness in our listing, nor are we endorsing any particular set of materials.²³

Most of the following materials have been developed and studied by researchers in physics education. In several cases, there is a significant body of evidence of improvements in student learning:²⁴

- *Real Time Physics* (Sokoloff, Laws, and Thornton, 1994, 1997) is a guide to microcomputer-based laboratory work designed to enhance stu-

²³More information about the materials, along with links to the publishers, can be found at the Web site of the American Association of Physics Teachers' Physical Sciences Resource Center, www.psrc-online.org [4/17/02]. Many of the publishers maintain Web sites of resource materials that may be useful to teachers.

²⁴This evidence is not specific to advanced high school physics courses. However, it is reasonable to expect that results from introductory college-level courses should generally apply.

dents' conceptual understanding of introductory physics topics. Studies of students using these materials have shown marked improvements in their understanding of concepts of kinematics and dynamics (Thornton and Sokoloff, 1990, 1998).

- "Physics Tutorials" (McDermott and Shaffer, 2002) are a combination of written exercises and simple experiments that can enhance student understanding of introductory physics topics. Designed primarily for use in introductory college courses to supplement conventional curricula, these tutorials would be appropriate and valuable for use in advanced secondary courses. The most complete set of such materials is that of the University of Washington Physics Education Group (McDermott, Shaffer, and Somers, 1994; Shaffer and McDermott, 1992; and Wosilait, Heron, Shaffer, and McDermott, 1999).

- *A Modeling Method for High-School Physics Instruction* (Wells, Hestenes, and Swackhamer, 1995) focuses on having students actively engaged in defining, building, understanding, and testing mathematical models of physical phenomena. Students compare their models with both traditional models and the results of experiments. The method focuses on model building, testing, and deployment (using the model in new situations) as a key scientific activity (Halloun, 1996).

- The *Workshop Physics Activity Guide* (Laws, 1997) is used as the main text for a 1-year calculus-based physics course (a traditional physics text can be used as a reference). The course features the use of integrated computer tools that students, working in small groups, use to collect, display, and analyze data and to develop mathematical models describing physical phenomena. Based on the results of physics education research, the guide uses a four-part learning cycle to have students (1) predict the results of an experiment, (2) reflect on the actual results and refine their predictions, (3) develop mathematical models with appropriate equations to describe the experiment, and (4) perform experiments to test the models (Laws, 1989, 1991, 1999).

- *Electric and Magnetic Interactions* (Chabay and Sherwood, 1999) is a calculus-based introductory physics course that emphasizes the development of conceptual models and scientific explanations of electricity and magnetism phenomena. Kits of scotch tape, batteries, lightbulbs, one-farad capacitors, and so on are used for "desk-top experiments" that introduce phenomena before students build detailed mathematical and conceptual models. The authors are just completing a text, *Matter and Interactions* (2002), to be used in the first semester of an introductory physics course. That text also emphasizes conceptual models and scientific explanations reinforced by computational studies of mechanical systems.

- *Six Ideas That Shaped Physics* (Moore, 1998) is a calculus-based course that organizes physics topics around six big ideas. Each chapter includes

many conceptual questions useful for in-class engagement, as well as a good collection of physics problems that require students to synthesize topics. The latter are particularly useful for collaborative learning groups. The book includes a good introduction to relativity, a section on quantum mechanics, and a section on thermal physics emphasizing a statistical mechanics approach. Early versions of the text were evaluated through the Introductory University Physics Program.²⁵

- *Physics: A Contemporary Perspective* (Knight, 1997) claims to be the first complete calculus-based introductory physics textbook reflecting the results of physics education research. It emphasizes a balance of qualitative and quantitative reasoning, multiple representations of knowledge, and a systematic approach to problem solving. A companion student workbook helps students develop conceptual and graphical understanding.

- The *CASTLE* curriculum materials developed by Pasco Scientific include material for investigating electricity, including batteries, lightbulbs, compass needles, and large capacitance capacitors. The focus is on developing conceptual models of electrical effects, particularly in circuits.²⁶

- *C3P: Comprehensive Conceptual Curriculum for Physics* is a high school curriculum that draws on materials from a variety of sources, including videos, inquiry methods, and laboratory experiments.²⁷

- Although not traditionally part of advanced physics courses in high schools, quantum physics may well be used as an optional or enrichment topic. A set of materials called *Visual Quantum Mechanics* has been developed by Dean Zollman and colleagues in the Kansas State physics education research group. The materials include simple experiments that illustrate basic quantum physics phenomena using light-emitting diodes, glow sticks, and other inexpensive equipment. Computer programs help students build conceptual models to explain the results of the experiments.

- Several publishers are revising traditional textbooks to take into account the results of physics education research. These revised texts emphasize student engagement in developing conceptual understanding, as well as improved approaches to problem solving. Already published is *Physics for Scientists and Engineers* (Serway and Beichner, 2000). In addition, a team of physics education researchers is producing a new version of *Fundamentals of Physics* (Halliday, Resnick, and Walker, 2000). This version is still in progress and should not be confused with the sixth edition of the textbook released in July 2000.

- Some other resources that might be used in an advanced high school physics course include the following:

²⁵A report on these evaluations can be found in Coleman, Holcomb, and Rigden (1998).

²⁶More information can be found on the Web at <http://www.pasco.com> [4/17/2002].

²⁷For further information, see the Web site <http://phys.udallas.edu> [4/17/2002].

—*PRISMS (Physics Resources and Instructional Strategies for Motivating Students)*—The primary materials include a teacher's guide with 120 activities for use with introductory physics students.²⁸

—PTRA Workshops and Manuals—The Physics Teacher Resource Agents program (sponsored by the American Association of Physics Teachers and the National Science Foundation) has developed a series of workshops and teacher resources for most of the topics taught in high school physics. The majority involve hands-on projects for students, as well as other teaching materials.²⁹

—*String and Sticky Tape Experiments* (Edge, 1987).

—*Conceptual Physics* (Hewitt, 1999).

—*Active Physics* (Eisenkraft, 1999)—This text is designed to be used as a “physics first” course, where students in ninth or tenth grade take physics before chemistry or biology. All of the units focus on applications of physics in everyday life, such as automobiles, home heating, and sound reproduction, with many hands-on activities.

²⁸Further information is available at <http://www.prisms.uni.edu> [4/17/2002].

²⁹Further information can be found at the American Association of Physics Teachers Web site by going to <http://www.aapt.org> [4/17/2002] and clicking on Programs and then PTRA.

5

Changing Emphases in Physics and Their Impact on Advanced Physics Instruction

The panel notes two changes in the practice of physics that should eventually be reflected in instruction in advanced physics courses in high school: the increasing use of computers in a variety of ways and a growing emphasis on interdisciplinary connections.

INCREASING USE OF COMPUTERS

The availability of easy-to-use numerical computation tools, graphical analysis programs, symbolic manipulation programs (e.g., MathCad, MAPLE, Mathematica), computer-based data acquisition, simulation programs, and the like is leading to dramatic changes in the practice of research in physics. As a result, there is somewhat less emphasis on detailed analytic calculations in many areas of physics research and an explosion of work in such areas as nonlinear dynamics and the study of complex systems, in which numerical and graphical tools are absolutely essential because traditional analytic methods fail. The panel argues that these same tools have the potential to effect major changes in the nature of introductory physics instruction.

The beginnings of those changes can be seen in the widespread use of computer-based and calculator-based data acquisition in introductory physics laboratory work. Computer simulations are also beginning to be used as a way of allowing students to explore actively the predictions and range of validity of various models of the physical world. These tools help introductory physics students build a better conceptual understanding of physical phenomena by actively exploring models and their predictions. Finally, and most provocatively, researchers have begun to pursue the use of computer programming as a medium and language for the study of introductory physics. In a manner that reflects the growing role of computational modeling in physics research, students may benefit by using computer programming as a means to express, explore, and refine ideas in physics (diSessa, 2000; Sherin, diSessa, and Hammer, 1993; Wilensky and Resnick, 1999).

The panel sees little in the current Advanced Placement (AP) and International Baccalaureate (IB) curricula that reflects these changes in the practice of physics. We note that although many AP and IB teachers do make use of computers in a variety of ways, neither the AP nor the IB examination assesses the use of computer tools. Accordingly, the panel makes the following recommendations:

- Advanced high school physics curricula should, over a period of time, evolve to include more use of computer tools in ways that are effective in physics instruction.
- Physics education researchers and others should continue to study the use of computers in introductory physics instruction (including advanced high school courses) to identify those uses that are particularly effective in promoting the instructional goals identified elsewhere in this report.

Eventually, cyberspace and information technology (CIT) may completely change the way new physical theories are developed. Instead of analytical models, theorists will use computer programs to conceptualize physical systems that cannot be adequately represented by traditional analytical methods. Students need exposure to such computer-assisted conceptualization as early as possible in their education. Therefore, the panel recommends that an appropriate unit in computer-assisted conceptualization be developed as soon as possible and made available to teachers of advanced physics courses as a possible optional topic (see Chapter 2 for a discussion of optional topics).

Capability for Rapid Information Sharing Among Physics Teachers

The primary opportunity afforded by the ever-expanding Internet is its promise of a new method of communication by which groups focused on particular sets of issues can rapidly interact to develop innovations. Teachers of advanced high school physics courses could form such groups to share and enrich their pedagogical skills. The opportunity now exists to create a national electronic clearinghouse of information relating to secondary school physics instruction. Box 5-1 presents a short list of some Internet groups that are already active.

Introducing Students to the Benefits of the Internet

Teachers of advanced high school physics are ideally positioned to introduce their students to the use of the Web and cyberspace technologies for carrying out research. Thus, the training of more computer-savvy profes-

BOX 5-1 Internet Groups for Physics Teachers

The following are some active Internet groups for physics teachers. The descriptions of these groups are taken from the article “Communities of On-Line Physics Educators” by Dan Maclsaac (2000):

- PHYS-L (Forum for Physics Teachers) is the largest with about 650 members and has the broadest membership. The list has a homepage located at <http://purcell.phy.nau.edu>, and this page links to archives of all postings since February 1996 and to list members’ personal Web pages at <http://members.xoom.com/exit60>. Together these form an outstanding set of resources.
- PHYSHARE (Sharing Resources for HS Physics Teachers) has about 600 subscribers and focuses on high school physics teaching issues. The list administrative address is listserv@lists.psu.edu, and postings must be made to physhare@lists.psu.edu.
- PhysLrnR (Physics Learning Research List) has about 475 subscribers and is focused on professional research into physics learning. This list maintains a private archive for postings, accessible to subscribers only. PhysLrnR maintains a large collection of specialist literature on Physics Education Research (PER) on an ftp server at <ftp://physlrnr.idbsu.edu/plrserve/pub/physlrnr>. The list administrative (or control) address is listserv@listserv.boisestate.edu, and postings must be made to PhysLrnR@listserv.boisestate.edu.
- TAP-L is a smaller list specializing in design and construction of physics laboratory and demonstration apparatus. Members are mainly college and university physics department demonstration and lab coordinators, and PIRA (Physics Instructional Resource Association) members. Postings are archived since 1999, and there is a list Web page at <http://members.odyssey1.net/kctipton/tapfaq.html>. Uniquely, this list runs a web ring of web sites run by the demonstration and laboratory coordinators at several dozen universities and colleges. The list administrative (or control) address is listproc@listproc.appstate.edu, and postings must be made to tap-l@listserv.appstate.edu.
- AP-PHYSICS is a list run by the College Board specializing in the teaching of AP Physics. Information on subscribing is available on the College Board’s website at <http://www.collegeboard.org/ap/listserv/list.html>.

SOURCE: Adapted from Maclsaac (2000). Also available on the Internet as a pdf file: <http://purcell.phy.nau.edu/phys-l/TPTApr00art.pdf> [4/23/02].

sionals could be naturally encouraged within advanced physics programs. If this is to occur, of course, computers will have to be widely available in classrooms, and their presence brings new concerns along with opportunities. The arrival of computers in the classroom is so new that there has not yet been a definitive evaluation of their impact on the learning process, either in general or within the advanced physics community

Revolution in Scientific Publishing

A revolution in scientific publishing is under way. Physics journals in particular are rapidly migrating toward electronic formats. Already some major U.S. laboratories have begun to phase out their actual libraries in favor of electronic access. Similar experiments have begun at the physics libraries of some of the nation's research universities. The whole physics publishing enterprise has been radically changed by the creation of electronic archives such as the Los Alamos <http://www.lanl.gov>. A decade ago only the single field of theoretical particle physics used this model. Today most fields of physics, mathematics, and other scientific disciplines are using it, and it has spread to the medical community through the recent creation of a server sponsored by the National Institutes of Health. It is clear that working research scientists already have a new manner of carrying out research. Both national and international collaborative scientific research efforts are supported through cyberspace. New research is created, posted on servers, and downloaded by other scientists, who then synthesize it and create their own new results at a more rapid pace than ever before.

Cyberspace Technology in College and High School Classrooms

In colleges and universities, experimentation with cyberspace technology and "new-technology classrooms" is beginning. Computers have already made their way into the traditional college physics laboratory, most significantly in the acquisition and analysis of data. In addition, many college instructors make themselves available to their students via e-mail, enabling questions and discussions to be undertaken at the convenience of both student and instructor. Literature searches are now often done electronically.

These developments have implications for the education of secondary school students currently engaged in the advanced study of physics. Various computer software programs are available for the tasks of communication (electronic mail, browsing on the Web, presentational tools, text editing, slide presentation [e.g., Power Point], and IR [infrared] personal response) and computer-assisted conceptualization (modeling environments, spread-

sheets, symbolic manipulation, mathematical graphing, computer-aided design, simulation and visualization, and data collection and analysis). All of these tools are used for a wide variety of research carried out by physicists. The panel recommends that these modern research tools be introduced as extensively as possible into advanced high school physics programs. The panel notes that many high schools are already using a number of these tools, especially software for data acquisition and analysis.

Communication Among Constituencies with an Interest in Physics Research or Education

The rapid speed of communication via CIT presents new opportunities for a closer relationship between the physics research and teaching communities. Many researchers at universities, government laboratories, and other organizations have created Web sites that are freely accessible and designed precisely for the purpose of making their research more available to the general public. The same can be said for the American Physical Society and other professional organizations of physicists.

It is therefore possible, as never before, to introduce topics of ongoing research to secondary school students currently studying advanced physics. Using CIT, researchers can best communicate the excitement of their research activity as they grapple with the scientific problems that lie at the boundaries of knowledge in the field. This excitement, when transmitted properly to students, can be a tremendous motivating factor leading them to consider scientific research as a career.

In addition, the Web allows easy access to university physics courses from outside university classrooms. Many professors offer Web-based mechanisms for their own students to monitor their courses. Often, course syllabi, homework assignments and solutions, and the like are made available via an appropriate Web site. Such mechanisms also offer exciting new possibilities for more closely linking physics instruction within the universities to that in secondary education programs. The panel recommends that CIT be used in the teaching of advanced high school physics to highlight current state-of-the-art research, thereby encouraging young people to join the nation's scientific workforce.

Future Uses of CIT in Advanced Physics Programs

There are a number of ways in which CIT poses challenges to be met in future advanced physics instruction. In this section, we outline the research needed to answer the question: "What might be the form of an advanced physics course in the year 2010?"

Because the possibilities are so vast, any categorization of the issues involved in answering this question is to some extent arbitrary. Nevertheless, we provide the following list of issues to provide a framework within which to conceptualize and begin to formulate specific goals and recommendations for the electronic advanced physics classroom of the not-too-distant future. The list is not meant to be exhaustive and is sure to grow as the nation's educational leadership becomes increasingly aware of the enormous opportunities presented by CIT:

- What is the appropriate use of CIT in teaching advanced physics courses?
 - In the teaching of advanced physics courses, how is it possible to foster a higher level of skill in the use of modern CIT to acquire, analyze, disseminate, and present data and information?
 - Is it possible to use CIT to close the gap between calculus-based and algebra-based physics courses by developing new computer-based modes of thinking about and handling conceptual and quantitative models of physical reality?
 - What is the best way to foster the development of high-quality CIT-based materials (e.g., hypertext) that will support the teaching of advanced physics courses?
 - What is the appropriate level of teacher training necessary for the effective use of CIT in an advanced physics course?
 - What are the appropriate standards of student attainment and proficiency in the use of CIT that should be required of a student enrolled in a high-quality advanced physics course?
 - What is the appropriate use of the Web as a medium for delivering distance learning in an effort to provide advanced physics instruction to the broadest possible population of students that can benefit from such training?

Potential Use of CIT to Administer Final Examinations in Future Advanced Physics Programs

In the not-too-distant future, CIT may be able to provide an efficient means of administering and scoring final examinations in advanced programs. If such a process is implemented, the panel makes two recommendations:

- It is absolutely essential that students retain the ability to return to and modify their answers to previous questions as they take the examination. Physics is a subject in which careful consideration and reconsideration are often required to find a correct solution to a problem. A fair physics test must reflect that essential feature of the discipline.

- The implications of adaptive questioning (in which succeeding questions depend on the responses given by the student to earlier questions) need to be carefully studied. The panel is skeptical that adaptive schemes can be devised that are truly fair to all candidates.

INTERDISCIPLINARY CONNECTIONS

An important issue for a field as ancient as physics is how it adapts to the needs of society in a given place and time. The field of physics today faces a period of transition. Among the most important reasons for this are the following:

- The period in which a primary national need for defense was fulfilled by physicists in creating, developing, and upgrading nuclear weapons has ended.
- A period in which technology is a primary driver of the national economy has begun.
- A period in which other areas of science, such as microbiology and genetics, will undergo rapid progress has also begun.
- The increasing availability, power, and sophistication of computational hardware and software will make possible novel quantitative descriptions of the physical universe. Society in general appears to be rapidly becoming more and more knowledge based. Enormous quantities of information are instantly available on ubiquitous computers. (See the discussion in the preceding section.)

Under these circumstances, the tasks that are undertaken by the field of physics must change both to meet the demands of society and to maintain the vitality of the field itself. Physicists, and the people trained by them, will need to be able to apply the body of knowledge developed within physics to totally new areas. In other words, physicists will be asked to become more interdisciplinary; they will have to apply their special knowledge and methods to problems that cross the boundaries of traditional disciplines. This fact has substantial implications for the training of the future physicists presently engaged in the advanced study of physics at the secondary level. It therefore makes sense to examine the two dominant advanced physics programs to determine the extent to which they provide suitable training to students along interdisciplinary lines.

The AP physics program appears to stick closely to the traditional curriculum that has been the hallmark of the field during the last 50 years. There appears to be no attempt within the program to address the increasing importance of applying physics knowledge across traditional field boundaries.

On the other hand, the IB program has several features that naturally allow students to begin to confront interdisciplinary issues. First, the IB program provides interdisciplinary options (biomedical physics, historical physics) that teachers may choose. Second, many questions from past IB examinations have an interdisciplinary flavor. Finally, during the Group 4 project component of the IB program, a collaborative group of students creates its own scientific investigation. Such projects can easily involve applying knowledge and methods from several different scientific fields.

Increased interdisciplinary content could be added to advanced courses by developing more separate units such as the biomedical physics unit found in the current IB program. Alternatively, the advanced course might choose examples illustrating how fundamental physical principles apply to a wide variety of areas. For example, the elastic properties of DNA molecules might be used to discuss the range of validity of Hooke's law for spring forces. Biological cell membranes could be used to construct interesting examples of electrical potential differences and electric fields.

The panel, in agreement with the National Research Council's (NRC) *National Science Education Standards (NSES)* (NRC, 1996), recommends that all advanced high school physics curricula include some experience with interdisciplinary applications of physics.

COMPARISON OF AP AND IB PHYSICS WITH EDUCATION STANDARDS

Extent to Which the AP and IB Physics Programs Reflect the Recommendations of the *National Science Education Standards*

The panel did not have sufficient time to make a detailed assessment of the extent to which the AP and IB Physics programs incorporate the recommendations of the *NSES* (NRC, 1996). The short answer to the question is "not much." As noted earlier, IB physics encourages interdisciplinary connections to some extent as recommended by the *NSES*.

Since most advanced courses in physics are designed to mimic college-level courses, and since the college-level courses are not (for better or worse) specifically designed with the *NSES* in mind, there is no immediate need for the advanced courses to be tightly tied to the standards. However, as more and more high schools adopt curricula in line with the *NSES*, college courses may evolve to take into account the new background that students then bring with them. We would then expect high school advanced courses to be redesigned as well.

Extent to Which the AP and IB Physics Programs Reflect the Recommendations in the National Council of Teachers of Mathematics Standards 2000

The National Council of Teachers of Mathematics recently published *Principles and Standards for School Mathematics* (NCTM, 2000). This document presents five principles and a series of standards to guide the teaching and learning of K–12 mathematics. The standards are grouped into several categories: Numbers and Operations, Algebra, Geometry, Measurement, Data Analysis and Probability, Problem Solving, Communication, Connections and Representations. Throughout the Principles and Standards is an emphasis on understanding, “Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge.” Indeed, “learning with understanding” may well be the clarion call of the entire document. The standards are intended as goals to be met by all K–12 students.³⁰

These standards do not directly address the issue of advanced physics study in high school. They do, however, provide a strong foundation on which advanced courses can be built. Certainly, it is desirable that any student undertaking the study of advanced physics in high school have met the NCTM standards before beginning that course. It should also be noted that high school physics courses in general, and advanced physics courses in particular, help students solidify their knowledge and skills in mathematics. Advanced physics courses are of special value in reinforcing skills in Measurement, Data Analysis and Probability, Problem Solving, Communication, and Connections and Representations.

³⁰More information on the standards can be found at the NCTM Web site: <http://nctm.org/standards/introducing.htm> [4/23/02].

6

Connecting Advanced High School Physics Programs with College Physics Programs

One of the principal rationales for advanced study in secondary schools is to enable capable and motivated students to do work that is beyond the normal secondary school level. Advanced study both removes an artificial cap on these students' learning in high school and facilitates their future learning in colleges and universities. Clearly, our success in nurturing our most talented students depends on just how well we accomplish this task.

QUALITY OF PREPARATION OF AP AND IB PHYSICS STUDENTS FOR FURTHER STUDY

The College Board presents evidence that students who do well on the Advanced Placement (AP) physics examinations perform in physics courses beyond the introductory level as well as, or perhaps even a bit better than, students who first encounter introductory physics in the standard college or university course (see, for example, College Entrance Examination Board, 1994c). About 10 years ago, one panel member administered the AP Physics B exam to students in that member's introductory college physics course. There was a good correlation between the students' performance on the AP exam and their grades in the college course.

Both these pieces of evidence can be interpreted as showing that scores on the AP physics exams are good predictors of success in college physics courses beyond the introductory level. Of course, one might legitimately question whether that is the primary *raison d'être* of advanced high school courses. One could argue, however, that for those students for whom college placement or credit is a goal the AP courses are reasonable substitutes for most introductory college-level courses.

The International Baccalaureate (IB) physics curriculum is not designed to be a substitute for college-level work. However, the panel believes the IB physics curriculum provides fine preparation for introductory college-level

work in physics. In terms of content, the IB physics curriculum is roughly equivalent to that of AP Physics B.

The demonstrated success of many highly qualified AP students in college courses beyond the introductory level confirms that these students can be as well prepared as those taking the introductory college course. However, there is evidence to suggest that the College Board's estimation that a score of 3 on an AP examination indicates a student is qualified for advanced placement may be too generous, and in practice most selective colleges require a score of 4 or 5 for placement or credit (Lichten, 2000). This latter practice is consistent with the panel's recommendation that a higher standard for qualification on a more conceptually oriented, less rushed examination would be an improvement (see Chapter 2). From this point of view, the successful skipping of introductory college courses by AP students might be construed as an indictment of introductory college physics courses rather than as an endorsement of AP courses.

DEPENDENCE OF COLLEGE PHYSICS PROGRAMS ON KNOWLEDGE GAINED FROM ADVANCED HIGH SCHOOL PHYSICS PROGRAMS

From the point of view of many college physics departments, there are serious problems with the interface between advanced high school programs and college physics programs. The content of AP courses is designed as an aggregate of the content of many large introductory science courses at major universities. Since these university courses vary widely, "averaging" their content into a single high school course produces a topic outline with greater diversity than any single university course. This holds especially true for the AP Physics B courses. As a result, the AP courses generally cover a content range that is very broad but not very deep. The courses tend to encourage memorization and technical problem solving without deep conceptual understanding, though that is of course not their intent. It is well established that learning of this kind is not easily generalized to new situations. Thus, the potential of physics education to contribute to the development of capable problem solvers is not fully realized.

In addition, there are many obstacles to creating a college-level instructional environment in secondary schools. For example, the rapid expansion of the AP program has caused a severe shortage of adequately trained teachers capable of teaching AP courses well (see Chapter 4). For these and other reasons, many of those responsible for granting advanced placement or credit in the colleges and universities doubt at present that students scoring 3 or 4, or in some cases even 5, on AP physics examinations actually have had experiences warranting the granting of such placement or credit, and some decline to do so. In addition, as noted earlier, many students who have

taken AP courses do not even take the AP examinations. The net result of this situation is that many students who have supposedly done college-level work in secondary school are destined to repeat that work once they enter college. Some even decide not to continue in physics rather than follow that path. While some of these students benefit from the college physics courses taken after an AP experience, the lack of coordination between secondary and higher physics education is problematic.

IMPROVEMENTS IN COLLEGE PHYSICS INSTRUCTION THROUGH A BETTER INTERFACE WITH ADVANCED HIGH SCHOOL PROGRAMS

College courses are subject to the same criticism of excessive breadth that has been made of advanced high school programs, as has been emphasized many times in the physics education research literature.³¹ These courses often fail both in improving students' conceptual understanding and in motivating them to continue. If high school programs of advanced study were to focus on a somewhat narrower but widely shared range of content, and if the learning process were to emphasize conceptual understanding, college and university physics courses could evolve to build on that content and understanding. For example, suppose that a deeper and more reliable knowledge of Newtonian mechanics could be achieved through advanced study in high school, as recommended in Chapter 2, with performance on examinations correlating well with established measures of conceptual understanding. Then college courses for graduates of advanced physics programs could reduce the time spent on mechanics and devote some of the time saved to topics that are conceptually difficult, such as electromagnetic fields. The net result would be enhanced student understanding at both levels.

It might also be possible, with some of the time saved, to include more contemporary physics.³² It is unfortunate that many of our most talented and advanced physics students spend 3 years surveying essentially the same material of classical physics (2 secondary years and 1 college year). As discussed earlier, their motivation and knowledge would be enhanced by some exposure to physics as it has evolved in the last few decades. This cannot be done properly in the time available unless some greater success in coordinating secondary and higher-level physics courses can be achieved.

³¹See Chapter 3 and the discussion of the Introductory University Physics Program evaluations in Coleman, Holcomb, and Rigden (1998).

³²The new IB physics syllabus includes particle production and annihilation; fundamental interactions; and an overview of leptons, quarks, and exchange bosons. The panel applauds the addition of these contemporary physics topics to the IB program.

Of course, not all students entering college will have studied advanced physics in high school, and that fact must also be taken into account when designing college course offerings. How to derive the optimum benefit from the physics background of incoming students is an issue that colleges will need to study carefully in the future.

RECOMMENDATIONS

The panel makes the following recommendations for creating a reliable interface between advanced high school and college physics programs:

- As discussed in Chapter 2, all advanced high school programs should seek to develop competence in Newtonian mechanics that emphasizes deep conceptual understanding, even if the coverage of other topics must be reduced.
- Final assessments must be modified to test for conceptual understanding and the ability to apply basic physical principles to situations not previously encountered.
- Colleges and universities and writers of textbooks should develop introductory courses and materials that take advantage of this enhanced understanding of Newtonian mechanics among the rapidly growing population of advanced high school program graduates. The amount of duplication between the high school and college courses could then be reduced, making possible a decrease in the excessive breadth of many of the college courses as well.

7

Main Findings and Overall Recommendations

This chapter summarizes the panel's main findings and overall recommendations. References to earlier chapters are provided to help the reader find more comprehensive discussion of these important issues.

1. The most important goals of advanced physics instruction are independent of the particular topics studied.

Advanced physics instruction should be aimed at generating excitement and enthusiasm for further study in physics, at achieving deep conceptual understanding of the subject matter covered, and at instilling in students the scientific habits of mind that are important for their further education in science. Learning any particular physics subject matter is of lesser importance (see Chapter 2).

2. All advanced physics programs should aim to develop deep conceptual understanding of the topics studied.

To achieve the above goals, it is essential that whatever topics are chosen be addressed in depth, with an emphasis on conceptual understanding rather than on technical problem-solving skills. Students must learn that physics knowledge is built on general principles and gain the confidence to apply those principles to unfamiliar situations (see Chapters 2 and 3).

It is critical that advanced physics programs allow enough time for extended debate, student-designed experimentation, and other activities necessary to develop depth of understanding. There must also be sufficient time for teachers to diagnose the current state of understanding of their students and to change their teaching techniques and objectives accordingly. Of course, it is impossible to assess the understanding of students without requiring them to explain their reasoning. The panel strongly recommends that explanations of reasoning be required from the first day of an advanced course,

so that providing such explanations quickly becomes automatic for all students in whatever they do in the course (see Chapter 4). For these reasons, very broad curricula, such as 1-year Advanced Placement (AP) Physics B courses, should either be extended to 2 years (as is done in International Baccalaureate physics) or eliminated in favor of more compact curricula that can be covered in depth (see Chapters 2 and 3).

3. All students of advanced physics should study a nationally standardized one-semester unit in Newtonian mechanics. This unit should have the coverage of current AP Physics C Mechanics (including rotational dynamics) but should not require formal calculus.

The study of Newtonian mechanics provides an ideal framework for developing the scientific habits of mind and deep conceptual understanding that are the primary goals of advanced physics instruction. Since familiarity with Newtonian mechanics is universally expected of students who have completed an advanced high school physics program, it is logical to create a standardized mechanics unit to serve as the foundation of all advanced physics study. College physics departments could then depend on a thorough knowledge of this unit in developing courses for the further education of advanced physics students (see Chapters 2 and 6). This new common unit should contain all the important physics currently found in the AP Physics C Mechanics curriculum, including rotational dynamics. To permit the study of the common mechanics unit by all advanced physics students, however, knowledge of formal calculus should not be required (see Chapter 2).

It is important to understand that the omission of formal calculus would have no adverse impact on achieving the important goals of advanced physics instruction. On the contrary, it would permit increased emphasis on conceptual understanding by eliminating the need to spend time studying calculus-intensive problems. For example, students would no longer need to be able to perform path integrals to find the work done by a force, but they would need to understand the connection between work and kinetic energy change. They would also have to be able to find the work done by a force that varies as a function of position by using the area under the force curve.

We note that this recommendation is in keeping with the recent trend on AP Physics C examinations to reduce the emphasis on mathematical complexity. When the concepts of calculus are essential to the development of the physics, these concepts can be introduced in other ways. For example, instantaneous velocity can be introduced as the slope of a tangent line to the graph of displacement versus time.

Finally, the panel stresses that the examination for the common mechanics unit is likely to be more difficult than the present AP Physics C Mechanics examination. For one thing, research has shown that students

have more difficulty with the kinds of conceptual questions that would make up the new examination than with problems that can be solved by mathematical techniques. In addition, successful students will be expected to be thoroughly familiar with the new mechanics unit, and the standards for success on the examination will be higher than they are now. The consolidation of mechanics into a single common unit does not by any means represent a lowering of present standards, but quite the opposite (see Chapter 2).

4. In a 1-year advanced physics program, students should study only one major area of physics in addition to Newtonian mechanics.

To keep the size of the curriculum manageable, the panel strongly recommends that 1-year programs cover only one other major area of physics beyond Newtonian mechanics. There should be great flexibility in the choice of the optional topic to be covered in the second semester, including the possible choice of a nontraditional unit designed to provide advancement by enrichment. (See Chapter 2.)

5. Meaningful real-world (laboratory) experiences should be included in all advanced physics programs. There is ample evidence that traditional “cookbook” laboratories do not meet this standard.

The panel strongly believes that real-world experiences are an essential part of advanced physics study. Science is distinguished from other ways of thinking by its reliance on evidence about the physical world and the importance of reproducible consistency in judging the truth of conjectures, laws, and theories. However, these experiences must be meaningful; that is, the educational benefits derived from the activities must be worth the time and effort expended. There is ample evidence that traditional cookbook laboratories do not meet this standard (see Chapter 2).

6. Teachers of advanced programs must be able to respond to their ongoing assessment of their students’ understanding (see Chapter 4).

Therefore, curricula that require spending specific amounts of time on particular subject areas or on certain kinds of activities should be avoided.

7. The scoring of written examinations must emphasize the evaluation of student understanding. A rigid scoring rubric in which points are awarded for very specific correct responses to small parts of each question is not appropriate; rather, the reader should evaluate the student’s response as a whole. A maximum score should be given only for complete and clear physical reasoning leading to the correct

conclusions. The recent trend toward increased emphasis on conceptual understanding should continue.

Because the final assessments in advanced programs involve high stakes, students and teachers tend to do whatever they must in order to score well on those assessments. This fact makes it absolutely imperative that the examinations measure the depth of understanding that is the fundamental goal of advanced physics instruction (see Chapter 2).

The assessment of understanding necessitates requiring students to explain their reasoning and evaluating those explanations. Since there is no way to anticipate all possible correct and incorrect explanations, it is impossible to perform this evaluation within the confines of a rigid scoring rubric. Current rigid rubrics must therefore be abandoned in favor of a more flexible approach in which each student's response is evaluated as a whole. This is the approach taken in grading essay questions in the humanities or social sciences, without any apparent problems due to lack of consistency in evaluation. Moreover, one member of the panel participated in an experiment in which AP physics examinations were graded in this fashion, and the consistency of the evaluation turned out to be at least as good as under the rigid scoring rubric (see Chapter 2).

8. The panel recommends that sufficient time be allowed for students to complete the entire final examination (see Chapter 2). Final examinations must measure what students know, not how fast they can recall and apply that knowledge.

9. The standards for success on final assessments should be raised.

The panel believes that if its recommended curriculum changes are implemented, successful students will know the material in the new, more manageable curricula thoroughly. Therefore, the panel recommends high standards of performance on the new final examinations (see Chapter 2).

10. More well-qualified teachers are desperately needed for advanced physics programs. A concerted effort should be made throughout the physics community to contribute to the training of highly skilled physics teachers. Peer assessment programs should be implemented for certification and continuing assessment of physics teaching skill.

With the continued growth of advanced physics programs across the nation, there is a severe shortage of qualified teachers for such programs. The panel endorses a concerted effort by all elements of the physics com-

munity to train more qualified teachers. It is also imperative that the salaries and professional status of physics teachers be raised to make them competitive with those of other professionals, so that sufficient talent will be attracted to the physics teaching profession (see Chapter 4).

The panel also recommends that, as is done in other professions (e.g., medicine), peer assessment programs be implemented for the certification of physics teachers and the continuing evaluation of their teaching skills. On this matter, we endorse the National Board for Professional Teaching Standards; however, we recommend that peer assessment be discipline specific rather than for all sciences.

11. The preparation and skill of the teacher are the principal factors that determine the ultimate success or failure of advanced physics instruction. Thorough understanding of the subject matter is a necessary but not sufficient condition for good physics teaching. Teachers must also be trained in the special pedagogy of physics.

The panel stresses that implementations of advanced physics programs differ widely from school to school. The way in which a program is implemented by a given teacher is often much more important than the choice of which program to implement (see Chapter 4).

12. Skilled physics teachers continually diagnose the understanding of their students and change their objectives and strategies as that diagnosis indicates. It is impossible to assess the understanding of students without requiring them to explain their reasoning. (See Chapter 4.)

13. Advanced courses should have greater interdisciplinary content and make increasing use of cyberspace and information technology.

Modern developments in both science and society as a whole indicate that physicists will be increasingly called upon to address problems that cross the boundaries between traditional disciplines (see Chapter 5). At the same time, the explosion of information technology provides a vast array of possibilities for improving advanced physics instruction (see Chapter 5). Teachers and administrators should be aware of these developments and help advanced physics programs expand their involvement in both areas over time.

14. Information technology should be used to create networks that will enable teachers, college faculty, and other professionals to share information useful for advanced physics teaching.

The Internet provides a rapid mechanism for exchanging ideas and information among professionals interested in advanced physics instruction. The panel encourages the continued expansion of networks of such professionals. Such networks are a powerful means of encouraging the creation of a professional community of physics teachers, consistent with the panel's recommendations for peer assessment (see recommendation 10) and greater emphasis on professional development (see Chapters 4 and 5).

15. Fairness must be ensured on future computerized final assessments for advanced physics programs.

The panel is aware that the use of information technology may allow more efficient administration of nationwide examinations for advanced physics programs. However, the panel stresses the importance of ensuring that these more efficient assessments remain fair to all candidates.

16. Given the scarcity of data on the long-term outcomes of physics education, an effort should be made as soon as possible to follow the progress of physics students over many years.

The panel believes there are far too few data on the long-term outcomes of physics education to allow important decisions about the physics education of large numbers of students to be made with confidence.

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Appendix A

Charge to the Content Panels from the Parent Committee

Charge to the Parent Committee and Content Panels: The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines.

Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the committee's charge and study questions.

The panels should focus on the following specific issues in advising the committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facili-

tate retrieval and application in new contexts (see, e.g., National Research Council [NRC], 2000).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?

2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?

3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of coverage with in-depth study of important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?

4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?

5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?

6. To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:

- a) students' mastery of content knowledge;
- b) students' understanding and application of concepts; and
- c) students' ability to apply what they have learned to other courses and in other situations.

2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience and independent investigation)?
2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The NRC's *National Science Education Standards* and the National Council of Teachers of Mathematics' *Standards 2000* propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?
2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?
3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix B

Biographical Sketches of Physics Content Panel Members

S. James Gates, Jr., the John S. Toll Professor of Physics, is the director of the Center for String and Particle Theory at the University of Maryland at College Park. His research focus is in mathematical and theoretical physics. Dr. Gates served on the National Research Council (NRC) Joint Strike Technical Review Panel and the Task Group I-Combat Power committee. He has taught university-level mathematics and physics for 30 years and has lectured on general education issues, consulted with the Educational Testing Service, worked on a municipal high school curriculum, and chaired the Howard University physics department. The Washington Academy of Science recognized him as its 1999 College Science Teacher of the Year. Dr. Gates received two B.S. degrees and a Ph.D. from the Massachusetts Institute of Technology.

David Hammer is an associate professor with joint appointments in Physics and Curriculum & Instruction at the University of Maryland, College Park. He conducts research in physics education, focusing on students' beliefs about knowledge and learning as well as on teachers' interpretations of the strengths and weaknesses in student thinking. Dr. Hammer earned his Ph.D. in Science and Mathematics Education and his MA in Physics from the University of California at Berkeley.

Robert C. Hilborn is the Amanda and Lisa Cross Professor of Physics at Amherst College, where he teaches introductory and advanced-level physics. Dr. Hilborn's current research focuses on testing the symmetrization postulate for identical particle systems in quantum mechanics, a study of the effects of dynamic Stark shifts on laser-excited atoms, and control schemes for chaotic systems. Dr. Hilborn is involved in physics education and has served as president of the American Association of Physics Teachers. In this position, he interacted with high school physics teachers and also has worked

with high school teachers while at Amherst. He is chair of the newly established National Task Force on Undergraduate Physics. Dr. Hilborn earned his Ph.D. from Harvard University.

Eric Mazur is at Harvard University where he is a Harvard College professor, Gordon McKay Professor of Applied Physics, and professor of physics. Dr. Mazur's research in optical physics includes contributions in light scattering, spectroscopy, and electronic and structural events in solids. Dr. Mazur also conducts research in improving science education, becoming well known for his "peer instruction" method for teaching large lecture classes. Dr. Mazur will complete his term on the Advanced Placement test development committee this spring. At the NRC, Dr. Mazur has served on the Working Group on Science Assessment Standards. Mazur received his Ph.D. in experimental physics from the University of Leiden in the Netherlands.

Penny Moore taught physics 60-percent time at Piedmont High School in Piedmont, California for twenty-five years and worked concurrently at the University of California, Berkeley. During this time she designed, obtained funding for, and directed three large national science education programs: The Science for Science Teachers and PRIME Science programs, both funded initially by the National Science Foundation, and The Journey Inside with Intel Corporation. In August 2000, she left a fulltime position in the physics department at Berkeley to work as director of Science and Math Education in the College of Mathematical and Physical Sciences at The Ohio State University in Columbus. At the NRC, Ms. Moore served on the Working Group on Science Assessment Standards and was a leader in assembling *Science Teaching Reconsidered*.

Robert A. Morse is a physics teacher at St. Albans School in Washington, DC, where he has taught physics and AP physics for 20 years. Dr. Morse has been recognized for his teaching with the Presidential Award for Excellence in Science Teaching, the Tandy Technology Scholar Award, the American Association for Physics Teachers (AAPT) Award for Excellence in Pre-College Teaching, and was named the American Physical Society Distinguished Physics Teacher for the District of Columbia for the APS Centennial. Dr. Morse has been active in the AAPT, where he has developed and presented workshops on teaching physics. At the NRC, he served as a panelist for the How People Learn Conference. He received his Ph.D. in Science Education from the University of Maryland at College Park, his M.Ed. from Boston University, and a BA in Physics from Cornell University.

Robin Spital (committee liaison and chair) is a teacher of Honors and Advanced Placement Physics at The Bolles School in Jacksonville, Florida. His career began at Illinois State University in Normal, where he was assistant professor of physics. He subsequently worked in the private sector as principal development engineer for the AAI Corporation in Hunt Valley, Maryland, and as principal scientist for Pfizer Medical Systems. Dr. Spital received his Ph.D. in theoretical high-energy physics from Cornell University.

Content Panel Report: Mathematics

Introduction

The National Research Council's Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed the mathematics panel to provide advice on the effectiveness of and potential improvements to programs for the advanced study of mathematics in U.S. high schools.¹ In accordance with its charge (see Appendix A) the panel focused its work on the Advanced Placement (AP) and International Baccalaureate (IB) programs.

A member of the parent committee chaired the panel. This individual also served as the panel's liaison to the committee and consolidated the panel's findings and recommendations into this report. The five other panel members represent university and high school mathematics faculty with a wide range of teaching experiences and a diversity of perspectives on mathematics education (for biographical sketches, see Appendix B).

In conducting this study, the panel examined two AP courses—Calculus AB and Calculus BC—and three of the four mathematics courses offered by the International Baccalaureate Organisation (IBO)—Mathematical Methods Standard Level (SL),² Mathematics Higher Level (HL), and Further Mathematics SL.³ The panel's analysis was informed primarily by a range of program materials, such as published mission statements, course outlines, teacher guides, sample syllabi, released examinations, and scoring rubrics provided by the College Board and the IBO; scholarly research related to the teaching

¹The mathematics panel is one of four panels convened by the parent committee. Each panel represented one of the four disciplines that were the focus of the committee's study: biology, chemistry, physics, and mathematics. The reports of the other panels and the report of the full committee are available at www.nap.edu/catalog/10129.html [4/23/02].

²It is the hours of contact time, not necessarily the level of course difficulty, that determines whether a course is designated as SL or HL.

³The panel did not review Mathematical Studies SL because it is a basic rather than an advanced course.

and learning of mathematics; and the combined experience and expertise of the panel members (College Entrance Examination Board, 1987, 1989, 1992, 1993, 1994, 1995, 1996a, 1996b, 1997a, 1997b, 1998a, 1998b, 1999a, 1999b, 1999c, 1999d, IBO, 1993, 1997, 1998a, 1998b, 1998c, 1998d, 1999a, 1999b, 1999c, 1999d, 1999e, 1999f, 1999g, 1999h, 1999i, 1999j, 1999k, 1999l, 1999m; Kennedy, 1997). The panel also considered two College Board studies addressing AP student achievement in college (Morgan and Ramist, 1998; Willingham and Morris, 1986) and several studies that examined the subsequent performance of IB students in college.⁴ The panel found surprisingly few other data on AP and IB on which to base its evaluation.⁵

For example, little is known, except anecdotally, about how either program is implemented in U.S. high schools, including the instructional strategies and resources used in individual classrooms, the structure of the syllabi in different schools, the quantity and quality of the facilities available, the preparation of teachers who teach the courses, and the ways in which students are prepared prior to enrolling in AP calculus or advanced IB mathematics courses. Information about the AP and IB assessments is also limited. The IBO currently conducts no systematic research addressing the validity,⁶ reliability,⁷ or comparability⁸ of its assessments across administrations. The senior examiners, not psychometricians, make determinations about the degree to which each administration is a valid and reliable measure of student achievement. The College Board, on the other hand, has gathered considerable data to demonstrate the reliability and comparability of student scores from one administration to the next and from one student to another. However, neither program has a strong program of validity research, and

⁴Downloaded from www.rvcschools.org in August 2000.

⁵Although few data currently exist, the panel notes that both programs have circulated requests for proposals to conduct research on the ways in which their respective programs are implemented in schools and classrooms and the effects of these different implementations on student learning and achievement. No data from any of these studies were available at the time this report was prepared.

⁶Validity addresses what a test is measuring and what meaning can be drawn from the test scores and the actions that follow. It should be clear that what is being validated is not the test itself, but each inference drawn from the test score for each specific use to which the test results are put.

⁷Reliability generally refers to the stability of results. For example, the term denotes the likelihood that a particular student or group of students would earn the same score if they took the same test again or took a different form of the same test. Reliability also encompasses the consistency with which students perform on different questions or sections of a test that measure the same underlying concept, for example, energy transfer.

⁸Comparability generally means that the same inferences can be supported accurately by test scores earned by different students, in different years, on different forms of the test. That is, a particular score, such as a 4 on an AP examination, represents the same level of achievement over time and across administrations.

neither has gathered data to document that the test items on its examinations measure the skills and cognitive processes they purport to measure. To fully analyze or evaluate the AP and IB assessments, it is necessary to know, for example, that test items intended to measure problem solving do in fact tap those skills and do not just elicit memorized solutions or procedures.

Further, little evidence is available for evaluating the long-term effects of the AP and IB programs. For instance, the panel could not find systematic data on how students who participate in AP and IB fare in college mathematics relative to other students. Nor could the panel find studies that examined the effects on postsecondary mathematics programs of the ever-increasing numbers of students who are entering college with credit or advanced standing in mathematics. While the College Board and a few colleges that receive IB students have conducted some isolated studies addressing how AP or IB students perform in college (see, for example, Morgan and Ramist, 1998), the inferences that can accurately be drawn from the findings of these studies are ambiguous (see Chapter 10 of the parent committee's report).

Because empirical evidence about the programs' quality and effectiveness is lacking, the panel focused its analysis on what the programs say they do, using available program materials. This report details the panel's findings about the programs based on its analysis of these materials, its advice to the committee regarding the major issues under its charge, and the types of evidence that are needed to enable more complete appraisal of the AP and IB mathematics programs—evidence that is urgently needed.

Before proceeding to report its findings and recommendations, the panel wishes to commend the College Board and the IBO for the ways in which they have responded to changes in the teaching of mathematics: AP by changing its syllabus and introducing technology; IB by introducing portfolio projects and technology. Both organizations have undertaken these changes in a balanced, reasoned way, with input from a wide range of communities. Considering that they are large organizations affecting thousands of students, teachers, universities, and colleges, both AP and IB have made significant and forward-looking changes remarkably successfully. The panel additionally commends the College Board for helping to bring together college faculty and high school teachers in collaborative efforts to improve the teaching of calculus across the secondary and postsecondary levels. These efforts have paid off in more coherent syllabi that are better aligned with what is known about the ways in which students learn mathematics.

While the IBO's collaborations with IB teachers are an important aspect of the development of IB programs and assessments, collaborations outside of the IBO network, for example, with professional disciplinary societies or colleges and universities, currently are not part of the approach taken to program development. As the IB program becomes more prominent in the

United States, the panel encourages the IBO to expand its collaboration efforts to include more members of the U.S. mathematics community. These types of collaborative efforts can increase public awareness of the program and its relationship to the calculus typically taught in U.S. high schools, colleges, and universities.

The remainder of this report is organized into five chapters. Chapter 2 provides an overview of the AP and IB programs in mathematics. Chapters 3 and 4 present, respectively, the panel's analyses of curriculum and assessment and of teacher preparation and professional development in the two programs. The impact of the programs is examined in Chapter 5. Throughout these four chapters, the panel's key findings are presented in *italic type*. Finally, the panel's recommendations are given in Chapter 6.

2

Overview of the AP and IB Programs in Mathematics

Although the Advanced Placement (AP) and International Baccalaureate (IB) programs serve similar populations of highly motivated high school students, the College Board and the International Baccalaureate Organisation (IBO) developed their programs for different purposes. These different purposes affect how the individual courses are developed, structured, and implemented; how student learning is assessed; and how assessment results are used. They also affect how teachers who are assigned to teach AP and IB courses are prepared and supported by the programs and what types of school resources must be allocated for the programs.

Detailed information about the history, mission, goals, and growth of the AP and IB programs is available from the College Board and the IBO (see the organizations' Web sites⁹). This report includes only information directly relevant to the panel's analysis, findings, and recommendations. A more complete discussion of the AP and IB programs can be found in the parent committee's report (Chapters 3 and 4, respectively).

THE ADVANCED PLACEMENT PROGRAM

Since its inception in the 1950s, the goal of the AP program has been to offer interested, motivated, and well-prepared students the opportunity to tackle college-level material and to earn college credit while they are still in high school. To this end, AP courses are designed to be equivalent to college courses in the corresponding subject area. Standardized, nationally administered, comprehensive achievement examinations that are offered annually in May provide a vehicle for students to demonstrate mastery of the

⁹www.collegeboard.com and www.ibo.org.

college-level material and to earn college credit or advanced placement in upper-level college courses with qualifying scores.¹⁰

The AP mathematics program consists of statistics¹¹ and two levels of calculus—AB and BC.¹² Both AB and BC concentrate on calculus of a function of a single variable. Consistent with the purpose of the program, AP courses are designed by a development committee comprised of university faculty, mathematicians, and master calculus teachers to be equivalent to many introductory college calculus courses with respect to the range and depth of topics covered, the kinds of textbooks used, the kinds work done by students, and the time and effort required of students (College Entrance Examination Board [CEEB], 1999a). This approach ensures that students have a smooth transition to college, but also means that any shortcomings in college calculus are likely to be transferred to advanced high school students.

AP courses are designed to represent generic introductory-level college courses. The determination of the content to include in AP calculus courses is based on information gathered from responses to an annual survey of college and university departments that offer general calculus courses in their institutions. It should be noted that the response rate to the survey is rather low (30–40 percent), calling into question the consistency of survey results with actual course syllabi in individual schools and in different types of institutions.

Each year the College Board publishes the *Advanced Placement Program Course Description: Calculus, AB and BC* (often referred to as the Acorn Book). This booklet includes a topical outline for the two calculus courses,¹³ sample examinations, and information about how previous AP mathematics examinations have been graded (see, for example, CEEB, 1992,

¹⁰The College Board allows colleges and universities to establish their own criteria for awarding credit or advanced placement. See Chapter 2 of the parent committee's full report for additional information on this issue.

¹¹Far more AP students enroll in AP calculus courses and take the related examinations than is the case for the statistics course, although the number of statistics students has been growing steadily since the course was first offered in the fall of 1997. To date, the College Board has identified 22,749 students who have taken both the AP Statistics and the AP calculus examinations; 54 percent took both examinations in the same year, 29 percent took the calculus examination first, and 17 percent took the statistics examination first (Gloria Dion, personal communication). Students who took both examinations earned slightly higher calculus grades than statistics grades.

¹²The AB curriculum is generally regarded as equivalent to one semester or two quarters of college calculus, whereas the BC curriculum is considered the equivalent of one year or three quarters of college calculus.

¹³The College Board publishes a separate guide for AP Statistics and for each of its other AP courses.

1996b, 1999b). Although the booklet is published annually, changes from year to year are usually small, and sometimes there are no changes.¹⁴

There are no AP calculus curricula in the true sense of the word; there are only topic outlines. The topic outlines are intended to indicate the scope of the courses, but they do not necessarily suggest the order in which the topics are to be taught, nor do they specify any particular pedagogy.¹⁵ Teachers are free to determine the order in which topics are introduced, and they are also encouraged to enrich their courses with additional topics as appropriate. Thus as implemented, the curricula for AP courses can vary from school to school in both sequence and emphasis. The resulting curricula are often more a function of the decisions made by individual teachers than decisions made by a centralized curriculum development group.

The topical outline for AP Calculus BC includes all of the topics from AP Calculus AB plus additional topics (see Appendixes C and D, respectively, for the AB and BC topic outlines for May 2000/May 2001). AB and BC students are expected to understand topics common to both courses at the same conceptual level. Both AB and BC calculus are designed to be taught over one school year.¹⁶ Decisions about which AP calculus course an individual student should select are generally based on both the school's offerings and the individual's abilities, achievements, and mastery of the prerequisite material.

The International Baccalaureate Diploma Programme

The IB Diploma Programme, created in 1968, was originally designed to serve a geographically mobile population, primarily children of diplomats, who relocate frequently but do not want to lose the continuity of their educational experiences. Thus, the program incorporates elements of several national systems without being based on any particular one. IB courses do not reflect the content and structure of college courses but rather what is believed by the program developers to be the full range of content knowledge and skills that should be mastered by well-prepared students prior to

¹⁴The course guide also alerts teachers to upcoming changes so they can prepare to teach the curriculum when it is implemented.

¹⁵A teacher's guide for AP calculus is available. This guide contains sample syllabi, lesson plans, and activities that have been used successfully by master AP calculus teachers in their own classrooms.

¹⁶The AB curriculum, although given only a semester of credit in college, is almost always taught over a full year in high school. The BC curriculum, which receives a year of college credit, is sometimes spread over more than a year in high school, beginning after one semester of precalculus.

study at the university level. Thus the courses are developed not to replicate college courses but to reflect an international conception of a well-designed college preparatory program of study among a small group of master teachers and discipline experts who design the courses using both their expertise and information gathered systematically from IB teachers in every IB school. A curriculum review committee with international membership is responsible for articulating, implementing, and maintaining the vision in each subject area. The mathematics committee is also responsible for specifying the presumed knowledge and skills (prerequisites) for each of the four IB mathematics courses.

The IB mathematics curriculum is substantially broader than the AP calculus curricula. IB offerings include four mathematics courses: Mathematical Studies Standard Level (SL), Mathematical Methods SL, Mathematics Higher Level (HL), and Further Mathematics SL. Each course has been designed to meet the needs of a particular group of students, and schools and teachers are encouraged to exercise care in selecting the appropriate course for each student.¹⁷ Courses that are designated as SL require a minimum of 150 hours of teacher contact time, while those designated as HL require a minimum of 240 hours of teacher contact time. As noted earlier, it is the hours of contact time, not necessarily the level of course difficulty, that determines whether a course is designated as SL or HL (IBO, 1993). For example, Further Mathematics SL is the most advanced mathematics course in the IB program. Both SL and HL courses include a common core of compulsory topics (105 hours for the SL courses and 195 hours for the HL courses), as well as one or more optional topics that are selected by individual teachers for their classes (45 hours for both HL and SL courses). Because the IB program has an international mission, this flexibility in curriculum enables schools to satisfy higher education entrance requirements in many countries.

The IB Mathematics HL course is taught over two years and includes as core material a substantial amount of calculus, roughly equivalent to the AP Calculus AB course, as well as substantial treatment of probability, algebra and trigonometry, complex numbers, mathematical induction, vectors, and matrices. In addition, the HL curriculum has optional units, one of which is taught in addition to the common core. There are units on abstract algebra, graphs and trees, statistics, analysis and approximation, and Euclidean geometry and conic sections. With the analysis and approximation option, the calculus coverage becomes roughly equivalent to that of AP Calculus BC.

¹⁷Mathematical Studies is taken primarily by students who do not expect to pursue mathematics or science in college. Students intending to major in science, mathematics, or engineering usually take Mathematical Methods SL or Mathematics HL, which serve a population comparable to that served by AP Calculus.

With the statistics option, the statistics coverage becomes roughly equivalent to the purely mathematical parts of AP Statistics (note, however, that AP Statistics devotes substantial attention to the nonmathematical aspects of statistics).

The IB program guides for the mathematics courses present the common aims and objectives for all Group 5 (mathematics) courses (see Box 2-1). The guides also provide a syllabus outline for each course (see Boxes 2-2 through 2-4). In addition to the syllabus outline, IB teachers are provided with a detailed syllabus that defines more explicitly what will be covered on the final examinations. The detailed syllabi include estimated teaching hours for each topic, but do not recommend a sequence for the presentation of topics (see Appendix E for an example of a detailed syllabus). IB mathematics program guides provide general guidance on instruction and offer specific suggestions regarding instructional strategies. The teaching notes also include suggestions for linking content to help students see connections, such as linking the study of the second derivative in the further calculus option to the study of exponents and logarithms in the core content. Teachers use the guides as the basis for determining the structure of their own curriculum. Thus as implemented, the curricula for IB courses, like those for AP courses, can vary from school to school in sequence and emphasis. Little is known about the nature of these variations and their effects on student learning and achievement.

Finding: The AP and IB programs are both designed to meet the educational needs of highly motivated and well-prepared students, but the origins, goals, purposes, missions, organizations, and structures of the two programs are very different. These differences contribute to variations in the educational expectations, opportunities, and experiences of students and teachers participating in the two programs.

AP AND IB TEST DEVELOPMENT

AP Program

AP calculus examinations are designed by a development committee comprised of high school teachers and university faculty in consultation with statisticians and psychometricians who attempt to create examinations that meet accepted standards for technical quality (American Educational Research Association/American Psychological Association/National Council on Measurement in Education, 1999). The development process incorporates the judgments of both disciplinary and psychometric experts. The AP calculus examinations are timed, with about 50 percent of the total time devoted to multiple-choice questions and the rest to free-response problem-

BOX 2-1 International Baccalaureate Mathematics Common Aims and Objectives

AIMS

- appreciate the international dimensions of mathematics and the multiplicity of its cultural and historical perspectives
- foster enjoyment from engaging in mathematical pursuits and develop an appreciation of the beauty, power, and usefulness of mathematics
- develop mathematical knowledge, concepts, and principles
- employ and refine the powers of abstraction and generalization
- develop patience and persistence in problem solving
- have an enhanced awareness of, and utilize the potential of, technological developments in a variety of mathematical contexts
- communicate mathematically, both clearly and confidently, in a variety of contexts

OBJECTIVES

Having followed any one of the programmes in group 5 (mathematics), candidates will be expected to:

- know and use mathematical concepts and principles
- read and interpret a given problem in appropriate mathematical terms
- organize and present information/data in tabular, graphical, and/or diagrammatic forms
- know and use appropriate notation and terminology
- formulate a mathematical argument and communicate it clearly
- select and use appropriate mathematical techniques
- understand the significance and reasonableness of results
- recognize patterns and structures in a variety of situations and draw inductive generalizations
- demonstrate an understanding of, and competence in, the practical applications of mathematics
- use appropriate technological devices as mathematical tools

SOURCE: Adapted from IBO (1997, 1998a).

BOX 2-2 Syllabus Outline Mathematical Methods—SL

The mathematical methods SL programme consists of the study of six **core** topics and one **option**.

PART I: Core **105 hours**

All topics in the core are compulsory. Candidates are required to study all the subtopics in each of the six topics in this part of the syllabus as listed in the *Syllabus Details*.

1	Number and Algebra	10 hours
2	Functions and Equations	25 hours
3	Circular Functions and Trigonometry	15 hours
4	Vector Geometry	15 hours
5	Statistics and Probability	20 hours
6	Calculus	20 hours

PART II: Options **35 hours**

Candidates are required to study all the sub-topics in **one** of the following options as listed in the *Syllabus Details*.

7	Statistical Methods	35 hours
8	Further Calculus	35 hours
9	Further Geometry	35 hours

PORTFOLIO **10 hours**

Five assignments, based on different areas of the syllabus, representing the following three activities:

- Mathematical investigation
- Extended closed-problem solving
- Mathematical modeling

SOURCE: Adapted from IBO (1997).

BOX 2-3 Syllabus Outline Mathematics—HL

The mathematical methods SL programme consists of the study of eight **core** topics and one **option**.

PART I: Core **105 hours**

All topics in the core are compulsory. Candidates are required to study all the subtopics in each of the six topics in this part of the syllabus as listed in the *Syllabus Details*.

1	Number and Algebra	20 hours
2	Functions and Equations	25 hours
3	Circular Functions and Trigonometry	25 hours
4	Vector Geometry	25 hours
5	Matrices and Transformations	20 hours
6	Statistics	10 hours
7	Probability	20 hours
8	Calculus	50 hours

PART II: Options **35 hours**

Candidates are required to study all the sub-topics in **one** of the following options as listed in the *Syllabus Details*.

9	Statistics	35 hours
10	Sets, Relations and Groups	35 hours
11	Discrete Mathematics	35 hours
12	Analysis and Approximation	35 hours
13	Euclidean Geometry and Conic Sections	35 hours

PORTFOLIO **10 hours**

Five assignments, based on different areas of the syllabus, representing the following three activities:

- mathematical investigation
- extended closed-problem solving
- mathematical modeling

SOURCE: Adapted from IBO (1998a).

BOX 2-4 Syllabus Outline Further Mathematics—SL

The mathematical methods SL programme consists of the study of six **core** topics and one **option**.

PART I: Core

105 hours

All topics are compulsory. Candidates are required to study all the subtopics in each of the five topics in this part of the syllabus as listed in the *Syllabus Details*.

As these five topics are identical to the options in part II of the mathematics HL syllabus, it will be presumed that candidates will have studied one of these topics as part of that programme. Consequently, this portion of the further mathematics SL programme is regarded as having a total teaching time of 140 hours.

1	Statistics	35 hours
2	Sets, Relations, and Groups	35 hours
3	Discrete Mathematics	35 hours
4	Analysis and Approximation	35 hours
5	Euclidean Geometry and Conic Sections	35 hours

PORTFOLIO

10 hours

Three assignments, based on different areas of the syllabus, representing at least two of the following four activities:

- mathematical investigation
- extended closed-problem solving
- mathematical modeling
- mathematical research

SOURCE: Adapted from IBO (1997).

solving questions.¹⁸ The development committees are responsible for deciding the general content of the examination and the ability level to be tested.

¹⁸These percentages do not necessarily reflect the weighting of scores as a final examination grade is determined.

Content specifications for AP calculus examinations are determined at the same time the topic outlines for the courses are developed. Examinations are constructed using the topic percentages from the AP course descriptions as a guideline for the distribution of questions. The development committee helps write and review test questions, as well as materials (including the AP course descriptions) that are distributed to schools. They work closely with College Board and Educational Testing Service (ETS) content specialists and psychometricians to ensure that the examination scores will mean the same thing from year to year and from student to student (CEEBS, 1999a).

For optimal measurement, the development committee endeavors to design a multiple-choice section such that the average raw score is between 40 and 60 percent of the maximum possible raw score. Questions at varying levels of difficulty are included. Some previously administered questions are included to link the current form of the examination to previous forms, thus maintaining comparability from year to year and examination to examination. The committees write, select, review, and refine free-response questions. One important aspect of test development is determining which item type and format are best for assessing a given topic or skill area. AP development committee members work with AP content experts and ETS statisticians in making this determination (CEEBS, 1999a). However, the College Board has not conducted any systematic research to determine whether particular test items actually measure the cognitive processes they purport to measure.

IB Program

IB mathematics assessments have two components—external and internal. The external assessment consists of a written examination that is administered internationally over a period of two days in May of each year (in November for split-session schools). The examinations test knowledge of both the core and optional topics. The internal assessment is a portfolio that represents the teacher's formative assessment of students' practical work judged against established assessment criteria.¹⁹ This component is conducted by teachers within the school environment and is moderated externally by the IBO. The Mathematical Methods SL portfolio consists of five assignments, based on different areas of the syllabus, representing the following three activities: mathematical investigation, extended closed-problem solving, and mathematical modeling. The Mathematics HL and Further Math-

¹⁹The portfolio component is new to mathematics. It was first used in 2000.

ematics SL courses add mathematical research to the list of activities from which students and teachers can draw portfolio activities.

The course guide, which includes a detailed description of the content, skills, and understanding students are expected to master during the course, serves as the test blueprint. Amplifications and exclusions are provided for each topic. They provide more explicit information on specific subtopics and help define what is and is not required in terms of preparing students for the examination (see, for example, IBO, 1997, 1998b, 1998c, 1998d).

New questions are written for each external examination. Unlike the College Board, the IBO does not develop its examinations in consultation with psychometricians. Rather, it relies on the expertise of its senior examining team to prepare a different form of the examination that is approximately of the same level of difficulty as previous examinations. Test items are not field tested prior to administration, and reliability is not calculated. Items are not repeated from one administration to another. After each examination session, a sample of candidate responses is closely scrutinized to determine whether they are in line with expectations for each question. In addition, the IBO solicits comments from teachers about the suitability of the examination papers in achieving the examination's objectives. Information gained in this manner is used in the preparation of future examinations. Like the College Board, the IBO does not conduct systematic research to determine whether particular test items actually measure the cognitive processes they are intended to measure.

3

Analysis of AP and IB Curricula and Assessments

To evaluate the appropriateness of the Advanced Placement (AP) calculus and International Baccalaureate (IB) mathematics programs for advanced high school students, the panel considered the degree to which the curricula and assessments of each emphasize four areas listed below. These areas represent the kind of mathematical learning the panel believes advanced mathematics students should experience in their high school calculus course:

- Technical skill, including flexibility with symbolic manipulation, graphical representation, numerical approximation, and function notation
- Conceptual understanding, including, for example, the derivative as a rate of change
- Theory, including precise definitions, carefully reasoned mathematical arguments, and mathematical rigor
- Applications and modeling, including situations in which students must set up the model (for example, choose a formula that represents a real situation)

CURRICULUM

AP Program

In the panel's opinion, the topics on the AP syllabi are appropriate and well connected. A strength of the AP curricula and examinations is their focus on reasoning that integrates graphical, algebraic, numerical, and modeling viewpoints. In its current formulation, AP calculus pays careful attention to the central concept of function and to connections among the common ways (numerical, graphical, analytical, and verbal) of representing functions. There is likewise careful attention to developing the main concepts of differentiation and integration, including several interpretations of and applica-

tions for each. However, because AP calculus courses are designed to be general-purpose courses, the applications to real-world problems and situations tend to be limited to those that are most manageable, both conceptually and technically. There are relatively few applications requiring deeper investigation that might prove more memorable and provide better opportunities for interpretation and modeling.

The panel views the content of the AP courses as sufficient, given the assumption that the preparatory coursework provides a solid foundation for calculus. There is considerable anecdotal evidence, however, that students intending to take calculus are rushed through prerequisite courses without learning the material well enough. Mathematical sophistication takes time and should not be confused with knowledge of a catalog of mathematical facts and techniques. Additionally, because the AP examinations create the focus for the curriculum, and they do so quite effectively, material not on the AP assessments tends not to be taught either in calculus or in the prerequisite courses.

Further, particularly able AP students could profit from an AP course enriched by modeling activities and more attention to proof. In this sense, the panel sees the AP calculus programs as minimal rather than maximal courses for advanced study. Teachers should be encouraged to challenge their students with problems that may go beyond the scope of the syllabi, teaching a course that is more demanding than the tests. Doing so would result in students having a richer learning experience. For the preparation of mathematicians, the panel views the slight attention paid to proof by the AP courses as a deficiency.

IB Program

The panel found that a broad factual base of information is provided by the IB curricula for Mathematical Methods Standard Level (SL) and Mathematics Higher Level (HL). The curricula encompass an introduction to elementary calculus (similar to the AP program's Calculus AB course) and additional areas of study selected by the teacher from among available options. However, the small number of hours suggested for study of each topic (50 hours for the introduction to calculus for Mathematics HL and 20 hours for Mathematical Methods SL) leads to the concern that students study each topic only at a procedural level. As compared with the AP program, the panel views the calculus portions of the IB curricula as "very traditional." For example, question #6 on the Mathematics HL exam, Paper 1, November 1999, reads:

The area between the graph of $y = e^x$ and the x axis from $x = 0$ to $x = k$ ($k > 0$) is rotated through 360° about the x axis. Find, in terms of k and e , the volume of the solid generated.

The panel views the branching away from calculus as a positive aspect of the IB program. Mathematics HL coupled with Further Mathematics SL requires students to show competence in elementary calculus, as well as an introductory understanding of probability, matrices and vectors, abstract algebra, graphs and trees, statistics, analysis and approximation, and either mathematical foundations or mathematical proof. While it would be wonderful for students to have an understanding of all these topics, the panel is concerned that the breadth of the curricula may force somewhat superficial coverage. The panel believes that a more beneficial alternative would be to help students develop a deeper and richer understanding of one or two of the mathematical topics and their applications.

The advanced options present teachers with an enormous challenge in trying to cover advanced material in a highly limited time frame. The abstract algebra option of Mathematics HL provides an example. In this option, both the extent and depth of the study of the subject are quite limited, necessarily so in view of the time available and the prior mathematical experience of the candidates. Therefore, the study of abstract algebra is confined to basic definitions and a few elementary properties. The focus is formal; no significant applications of groups are given. The difficult part of learning about groups is not the formal definitions and elementary properties but understanding why the ideas are important. The panel believes it is more useful for students to study deeply topics that are closer to the high school curriculum, such as the study of solutions of polynomial equations (with emphasis on 3rd- and 4th-order equations), the use of transformations in plane geometry, or elementary number theory. Students with these topics in their background will be better prepared to appreciate later the significance of group theory.

The IB curricula provide a strong foundation in the key concepts of college preparatory mathematics. The syllabi and the assessments, however, do not appear to promote the relationships among the mathematical concepts learned. The syllabus for Further Mathematics SL states: "At this level, less emphasis should be put on departmentalizing the various topics and more emphasis should be given to the links between topics. For example, the knowledge of complex numbers, recurrence relations and Newton's method could be brought together in a brief introduction to fractals." However, the assessment materials do not support this linkage but are strictly departmentalized. Waiting until the final year of advanced study to emphasize the links among topics with the portfolio assessment is too little, too late.

Finding: The AP curricula are largely sound. The recently revised syllabi with more emphasis on conceptual understanding have significantly improved

the program, although further change in this direction is desirable. The panel also believes the focus on reasoning should be increased.

Finding: The IB curricula are largely sound. The portfolio requirement, with its emphasis on applications of mathematics, is likely to introduce a focus on modeling that will benefit IB students. However, the calculus sections of the syllabi do not place enough emphasis on conceptual understanding. The panel also has some concern that the breadth of the curricula, although an attractive feature of the program, could lead to superficial learning.

Finding: AP and IB curricula are designed to prepare students for successful performance on end-of-course examinations. The content and structure of the examinations, therefore, have a profound effect on what is taught and how it is taught in AP and IB classrooms.

ASSESSMENTS

Research indicates that the problems students solve as part of their classes have a significant effect on the strength of the background they acquire. Since the types of problems that are on the end-of-course assessments largely determine the structure and content of classroom and homework problems, evaluation of the effectiveness of the programs must include an evaluation of the problems on the examinations.

AP Program

On the basis of the four areas of emphasis described above, the panel believes the AP examinations should include questions that emphasize the following:

- Complex problems that may require significant technical skills
- Problems that probe students' conceptual understanding and take into account what research tells us about common misconceptions
- Problems that require mathematical reasoning, clear exposition, and the ability to write precise mathematical statements
- Problems in which students must construct a mathematical model from a verbal description

The panel reviewed 5 years of publicly released AP Calculus AB and AP Calculus BC examinations, related course descriptions, teachers' guides, and scoring rubrics (College Entrance Examination Board [CEEB], 1989, 1993,

1997a, 1998a, 1999b, 1999d). This review focused primarily on the examinations that were administered after 1998, when the revised AP calculus courses were fully implemented. The following findings with regard to the AP calculus examinations (both AB and BC) emerged from the panel's review.

Technical Skill

The goals of the AP program explicitly support the development of strong computational skills, both by hand and using technology. There is a reasonable balance of symbolic and graphical problems on AP calculus examinations. However, there are not many numerical problems, and more would be an improvement. The division of the examinations into two parts—one that allows the use of a graphing calculator and one that does not—is useful, ensuring that students acquire skills with both symbols and numerical approximations.

The need to cover in one $1\frac{3}{4}$ -hour multiple-choice test all of the material from two semesters of calculus makes the tests broad with limited depth; thus, for example, only a modest amount of time is available for solving each problem. As a result, the chain rule is tested at a superficial level, and only routine integration-by-parts questions are given. Seldom do Taylor series questions go beyond the basics, for example, rarely to a composite series such as the first five terms of $\sin(x^2)e^x$.

Student achievement on the examinations confirms that the goals for technical skills are not being met at a high level. The College Board's analysis of grades earned on the 1998 AB examination indicated that fewer than 15 percent of the students who earned a 3 obtained a score above 23 out of 45 on the multiple-choice questions.²⁰ Most of these multiple-choice questions tested very basic calculus knowledge. The panel speculates that the underlying reason students could not answer these questions was poor algebra skills rather than a lack of understanding of the necessary calculus. For example, on the 1998 AB exam, 75 percent of students who earned a grade

of 3 were able to evaluate the integral in question #3, $\int \frac{dx}{x^2}$, but only 38 percent were successful when they had to separate the fraction and then

integrate in question #7, $\int \left(\frac{x^2 - 1}{x^2} \right) dx$.

²⁰The College Board provides this type of information to teachers with score reports and with released examinations (CEEB, 1998a, 1998b). The multiple-choice score is calculated by giving one point for each correct answer and subtracting $\frac{1}{4}$ point for each incorrect item.

It also appears that AP students taking the examination had not had enough practice solving nonstandard problems. For instance, on the 1998 AB exam, 75 percent of the students were able to differentiate the “harder” implicit function in question #6:

$$\text{If } x^2 + xy = 10, \text{ then when } x = 2, \frac{dy}{dx} = .$$

However, only 36 percent were able to figure out that the second derivative of a linear function is zero and then integrate in question #11:

$$\text{If } f \text{ is a linear function and } a < x < b, \text{ then } \int_a^b f''(x)dx = .$$

Question #3 of the free-response section of the 1998 AB examination was a problem about motion in which information was given in a graph and table, rather than the more usual formula. The score on this question (average 2.9 out of 9) was much lower than the scores on the two multiple-choice questions in which the position was given by a formula (questions #14 and #24, with 94 percent and 52 percent correct, respectively). This result suggests that although students had learned how to answer questions like #14 and #24, they had not fully understood the concept. The panel includes these data to illustrate its contention that some AP students can do very well on AP calculus examinations without understanding the underlying concepts. Further analysis of this kind is necessary and should be part of a systematic program of validity research.

Conceptual Understanding

In recent changes to the syllabi for AP calculus, the emphasis on calculus as a collection of techniques has decreased, and the emphasis on conceptual understanding of fundamental principles has increased. The panel applauds this change. The current syllabi and examinations acknowledge the importance of techniques but do not allow them to overwhelm the course.

AP assessment items emphasize the major concepts of calculus (e.g., functions, derivative, integral, the Fundamental Theorem). Furthermore, the items incorporate current perspectives on learning by emphasizing multiple representations (i.e., the rule of four) and by placing some items in real-world contexts. However, there are missed opportunities to include questions that address common student misconceptions identified by educational research (for example, in understanding the derivative, slope fields, and functions). In addition, the test does not place enough emphasis on ensuring that students are fluent with the symbolic language.

AP examination problems also sometimes reinforce the idea that mathematics is essentially procedural. The questions may be divided into so many parts that they become exercises in following instructions rather than in

choosing a strategy to solve a problem. For example, in 1998, the following problem was given on the AP Calculus BC exam:

A particle moves along the curve defined by the equation $y = x^3 - 3x$. The x -coordinate of the particle, $x(t)$, satisfies the equation

$$\frac{dx}{dt} = \frac{1}{\sqrt{2t+1}},$$

for $t \geq 0$ with initial condition $x(0) = -4$.

- (a) Find $x(t)$ in terms of t .
- (b) Find $\frac{dy}{dt}$ in terms of t .
- (c) Find the location and speed of the particle at time $t = 4$.

Note that parts (a) and (b) of this problem lead the student to the solution of part (c). Thus, solving this problem successfully involves executing each step correctly and seeing the connections among them. But suppose parts (a) and (b) were omitted. The problem would then take on a very different character: it would test whether a student can find a path to the solution rather than execute steps. The most talented students—those in BC Calculus—should have more practice with problems in which they must design a method or solution.

Theory and Proof

Theoretical questions do not appear explicitly on AP examinations; there is little emphasis on proof in the AP syllabi. In the last decade, however, the emphasis on conceptual understanding has increased in the examinations. For example, in the 1998 syllabi, the movement away from a “laundry list” of topics encouraged students to think about the key ideas rather than memorize problem types. The panel applauds this change. Indeed, further change in this direction would be welcome. The panel recommends the inclusion of one or two items that assess students’ understanding of the definition of the derivative. By this we mean including problems that assess understanding of the meaning of the definition of the derivative, not the ability to compute using the definition.

Applications and Modeling

The AP program does not make a sufficient attempt to connect calculus with other fields in a realistic way. There is a tendency to use applications of rather ritualistic and formulaic kinds and of limited difficulty. The test con-

centrates on a few prescribed applications (e.g., calculation of volumes) or gives applications that consist largely of interpretation of symbols or computations in a new context. Its problems have a “whiff” of application, but they are often jarringly unreal at a deeper level. For example, question #5 of the free-response section of the 1995 AB examination states:

. . . [W]ater is draining from a conical tank with height 12 feet and diameter 8 feet into a cylindrical tank that has a base area 400π square feet. The depth h , in feet, of the water in the conical tank is changing at the rate of $h - 12$ feet per minute.

And question #1 on the 1995 BC examination reads:

A particle moves in the xy plane so that its position at any time t , $0 \leq t \leq \pi$,

is given by $x(t) = \frac{t^2}{2} - \ln(1+t)$ and $y(t) = 3 \sin t$.

It is difficult to imagine mechanisms that would make liquid or particles behave as described in these problems. In their attempt to make mathematics seem real, items of this sort may in fact contribute to the sense of many students that mathematics is disconnected from reality.

There is also a paucity of problems requiring substantial background development or technical facility for their solution. For example, there are no modeling problems in which students have to construct a function in an unfamiliar context. Students whose encounter with calculus does not include substantial applications and difficult problems are not likely to regard calculus as the immensely useful problem-solving and explanatory tool it in fact is. The panel notes that the portfolio component of the IB program does require students to perform mathematical investigations, extended closed-problem solving, and mathematical modeling.

The panel is concerned that the need to standardize AP has led to a course with the rough edges smoothed out as much as possible. However, a real appreciation of the subject may require experiencing those rough spots. This is the analog of laboratory work for science courses.

In conclusion:

- The AP examinations are closely aligned with the topics included in the related “Course Description for the AP Calculus Program.”
- Students who do well on the AP examinations can be considered fluent in the basic operations and key ideas of calculus.
- The AP examinations are light in their expectations of technical skill (severity of symbolic calculations) and theory (precision in argument).
- The AP examinations do not place enough emphasis on critical thinking, communication, and reasoning.

- The problems on the AP examinations do not appear to be sufficiently difficult to fully assess important skills and conceptual understanding.
- The AP examinations should include questions that ask students to interpret/explain their results.
- The word problems used on the AP examinations are limited in scope. The examinations try for a veneer of reality by including problems that appear to be taken from real-life situations (e.g., water draining and particles moving), but better applications are needed.
- The types of problems included on the AP examinations are somewhat formulaic and predictable from year to year. This creates a situation that encourages teachers to teach problem types rather than focusing on the development of students' problem-solving skills and mathematical thinking. Research shows that when teachers know what problem types to expect on an examination, their students tend to focus on lower-level problem-solving behaviors.
- It is the consensus of the panel that the AP examinations would be greatly improved and would encourage better teaching practices if they included fewer predictable problems and more challenging and interesting problems.

Finding: The AP examinations have improved under the current syllabi. The effort to promote conceptual understanding by asking nonstandard questions and requiring verbal explanations is excellent. For example, the fact that there is now a wider variety of applications of integration (and not from a prescribed list) encourages students to think about the meaning of an integral. The inclusion of graphing problems involving a parameter focuses attention on the behavior of a family of functions. The variety of representations of a function—by a graph and a table as well as by a formula—promotes a better understanding of the concept of function. However, the examination is still predictable enough for many students to do respectably well by mastering question types rather than concepts. The examination does not include enough problems that focus on conceptual understanding. More problems are needed that involve multiple steps, test technical skills in the context of applied problems, ask for interpretation and explanation of results, include substantial realistic applications of calculus, and test reasoning or theoretical understanding.

The panel acknowledges that including problems such as these on AP examinations, while providing important information about student learning and understanding, could increase testing time and add complexity to the scoring process. A careful analysis of the pros and cons of changing the AP examinations along the lines suggested above should therefore be conducted.

One possible solution to this dilemma might be to use multiple measures of student achievement that are administered over a period of time to compute a final AP grade, rather than to maintain exclusive reliance on a single 3-hour examination for determining what students have learned over 5 years of mathematics instruction.

IB Program

In conducting its analysis of the IB assessments, the panel reviewed the May and November 1999 examination papers for Mathematical Methods SL and Mathematics HL, the Group 5 Mathematics Guide (1993), and the 1998 updated course descriptions for Mathematical Methods SL and Mathematics HL, all published by the IBO (International Baccalaureate Organisation, 1999a, 1999b, 1999c, 1999d, 1999e, 1999f, 1999g, 1999h, 1999i, 1999j, 1999k). The panel's analysis of the IB examinations suggests that considerable conceptual understanding is required for students to do well. However, the current level of emphasis on procedural knowledge does not appear to be appropriate given emerging research on the relative importance of conceptual knowledge. It appears that opportunities are missed throughout the examinations to connect procedural knowledge with conceptual knowledge. The panel is concerned that the procedural aspects of the IB examinations could lead to superficial instruction in the mathematics. The mathematical investigations, extended closed-problem solving, mathematical modeling, and mathematical research options for the internal portfolio assignments are a large step in the right direction to mitigate this problem.

Technical Skill

The overall technical level of the IB examinations is high compared with typical U.S. high school expectations. Some IB examination questions demand levels of technical accomplishment that the AP Calculus BC examination does not attempt. For example, the May 1999 examination for Mathematics HL, Paper 2, contains the following question 8, part (ii):

(a) Using the trapezium rule and Simpson's rule with 6 subintervals, evaluate the integral

$$\int_0^1 g(x)dx,$$

where $g(x)$ is given at seven points by the following table.

x	$x_0 = 0$	$x_1 = 1/6$	$x_2 = 2/6$	$x_3 = 3/6$	$x_4 = 4/6$	$x_5 = 5/6$	$x_6 = 1$
$g(x)$	1	0.97260	0.89483	0.77880	0.64118	0.49935	0.36789

- (b) Find the error estimate for Simpson's rule in terms of $g^{(4)}(x)$.
- (c) When $|g^{(4)}(x)| \leq 6$, determine the number of subintervals required to use Simpson's rule to obtain a value for the above integral, which is correct to five decimal places.

Items in Further Mathematics SL frequently require a high level of computational skill. Research on learning suggests that procedural fluency also influences students' ability to utilize their mathematical knowledge. As a result, although the panel calls for an increase in conceptual focus, we do not advocate a decrease in the level of computational skill required.

Unlike the AP examinations, all IB examinations allow the use of calculators. The calculators must be of a preapproved type, which include graphing calculators, but not those with a computer algebra system. Although the IB examinations require substantial skill with symbol manipulations, they do not require much graphical and numerical skill. Few problems are primarily graphical or numerical. The numerical problems that appear more often concern numerical algorithms rather than use of numerical data.

The algebraic skills required for success on the IB examinations are impressive. The examinations often involve the use of parameters, which increases the difficulty of the resulting algebra. Most computations in the questions in Part 1 require two steps. For example, on the May 1999 examination for Mathematics HL, Paper 1, questions #6 and #12 are the following problems:

6. Find the value of a for which the following system of equations does not have a unique solution.

$$4x - y + 2z = 1$$

$$2x + 3y = -6$$

$$x - 2y + az = \frac{7}{2}$$

12. Given $f(x) = x^2 + x(2 - k) + k^2$, find the range of values of k for which $f(x) > 0$ for all real values of x .

The calculus included on the IB examinations is basic and focuses primarily on techniques. The functions do not appear to be chosen to simplify the computations. For example, in question #14 on the May 1999 examina-

tion for Mathematics HL, Paper 1, students were given $g(t) = \frac{\ln t}{\sqrt{t}}$ and asked

to find the interval where $g''(t) > 0$. However, the Subject Report coauthored later by the chief examiner and two deputy chief examiners states, "the errors resulting from messy answers [for $g'(t)$] were sad." (IBO, 1999m). The

fact that substitutions for integration and techniques for solving differential equations were given explicitly to the students greatly—and in the panel’s opinion, inappropriately—reduced the level of technical calculus skill required. Problems such as the following appear to be typical:

Using the substitution $u = \frac{1}{2}x + 1$, or otherwise, find the integral

$$\int x \sqrt{\frac{1}{2}x + 1} dx .$$

Conceptual Understanding

Few questions on the IB examinations are focused explicitly on conceptual understanding. Many problems could be done procedurally if the teachers had taught this way or if students had done enough practice problems. However, there is such a broad range of topics on the examinations that it would be difficult for students to do well without understanding mathematical concepts.

The IB examinations test conceptual understanding indirectly. Many questions require a significant level of understanding to be solved in a practical manner. For example, consider question #16 from the May 1999 Mathematics HL exam, Paper 1:

Given that $(1 + x)^5 (1 + ax)^6 = 1 + bx + 10x^2 + \dots + d^6x^{11}$, find the values of $a, b \in \mathbb{Z}^*$.

It is unreasonable for a student to multiply out the two expressions on the left to solve this problem; in practice, the student needs to understand which terms of the binomial expansions contribute to the unknown terms on the right. Problems requiring this level of conceptual understanding are not uncommon.

Very few IB examination problems require interpretation. Some IB questions also lead the student too much. In such cases, the student often does not need to decide what to do, as this is specified by the question; the “question” revolves around whether the student can perform the appropriate procedure accurately. (The integration problem on substitution given above is of this type.)

Theory and Proof

Few problems on the IB examinations involve anything resembling theory. Paper 2 of Mathematics or Further Mathematics may include problems on induction, as well as some problems requiring students to “prove” a simple

statement (for example, to show that $\cos x + \cos 2x$ is periodic and even). However, many of these “proofs” involve only one step or a computation.

Applications and Modeling

The questions on the 1999 IB examinations for Mathematical Methods SL and Mathematics HL make almost no attempt to connect calculus with the real world (although the graph theory and statistics questions do feature quasirealistic settings). However, there is an emphasis on mathematical models in the portfolio section, which was initiated in 2000.

There were no problems on the 1999 IB examinations for Mathematics Methods SL and Mathematics HL in which students needed to develop a mathematical model. The statistical problems on the examinations were stated in an applied context, but the students were never required to decide what statistical technique was appropriate for that setting. Some problems had unrealistic modeling settings; others had settings that were never involved in the solution. For example, question #20 on the May 1999 examination for Mathematics HL, Paper 1, reads:

A particle moves along a straight line. When it is a distance s from a fixed point, where $s > 1$, the velocity v is given by $v = \frac{(3s + 2)}{2s - 1}$. Find the acceleration when $s = 2$.

In conclusion:

- Including more conceptually focused prompts could strengthen IB test items. This shift in focus would increase the likelihood that instruction would assist students in both overcoming common misconceptions and acquiring a deeper understanding of the mathematical ideas.
- Some IB questions are too focused on procedure. For example, almost all the integrals to be done by substitution have the substitution given explicitly. This has the effect of making the substitution problems “plug and chug.” Instead, students could be asked to (1) decide that the integral should be done by substitution and (2) be able to select an effective substitution.
- The IB examination could be improved by including more conceptually focused prompts in items designed to assess students’ techniques for computing solutions.
- The IB examinations could include prompts that demonstrate the ability to use computational procedures in solving complex problems.

The panel acknowledges that including problems such as these on IB examinations, while providing important information about student learning and understanding, could increase testing time. However, some IB testing

time might be recaptured and used more effectively if the IBO eliminated the easy prompts that are included to make students feel more comfortable in the testing situation and replaced them with the types of items described above. A careful analysis of the pros and cons of including more complex problems on the IB examinations should be conducted before a decision is made about how to accomplish this task.

Finding: The IB examinations benefit from being more varied than the AP examinations. However, a few examination questions are at too low a level as they ask students to perform algorithms specified in the problem. The examinations should include more problems that focus on conceptual understanding, and do not include enough problems that test whether students know which algorithm to apply (e.g., integration by substitution), test technical skills in the context of applied problems, ask for interpretation and explanation of results, and include substantial realistic applications.

Examination Practices

Beyond their impact on curriculum and pedagogy, AP and IB examinations play a critical role in student learning. Students who do not take the examination at the end of an AP or IB course are less likely to have a college-level experience. Virtually all of the students in IB mathematics courses take the end-of-course examination. Although the panel was unable to obtain precise figures, the director of the North American IBO office estimated that more than 90 percent of IB students take the examination. In contrast, College Board data suggest that nearly 40 percent of the students who enroll in AP calculus courses do not take the exam. It is unclear why this is so. Some students may decide not to take the examination because they expect not to do well. Others may not take it for financial reasons or because they plan to matriculate at a college where the score will not count. Since schools pay the College Board in June only for the examinations that are taken, many schools allow students to opt out at the last minute. It also is possible that because schools are under increased scrutiny for quality and AP examinations may be misused as a measure of quality, weaker students in AP courses may be discouraged from taking the examinations, thereby eliminating potentially low scores from the school's analysis (see Chapter 10 of the parent committee's report for further discussion of this issue).

Finding: Students who do not take the examination at the conclusion of an AP or IB course miss the opportunity to pull the material together for themselves. They also have a negative effect on the experience of other students by making the course appear to be less serious.

COMPARISON OF AP AND IB SYLLABI AND EXAMINATIONS

Comparison of the AP and IB syllabi and examinations led the panel to make the following observations:

- Students who take AP Calculus AB or BC and AP statistics will likely know more calculus and more statistics but may know less precalculus (particularly vectors) than a student who completes an IB mathematics program.
- Students who take IB mathematics will likely know more statistics than those who take AP Calculus AB or BC without AP statistics. The IB program provides more variety in topics than the AP program and appears to provide more quality assurance in the areas of algebra and trigonometry. As yet, however, there are no data on this point.
- Both AP and IB examinations have little emphasis on modeling. However, the IB examinations reflect even less of an attempt than the AP examinations to connect to the real world.
- The AP calculus examinations are still fairly predictable, even after the recent revisions to the syllabi. The IB examinations appear to be less consistent in style and content than the AP examinations, leading the panel to wonder whether IB questions are required to undergo less psychometric screening than AP questions. This situation has advantages and disadvantages. There is less predictability in the IB examination in any given year, and some innovative questions are included, such as question #3 on the November 1999 examination for Mathematics HL, Paper 2. Others, such as

the question involving $g(t) = \frac{\ln t}{\sqrt{t}}$, benefit from not having been constructed primarily so they would be easy to grade. However, some IB problems suffer from apparently not having had the level of revision typical of AP questions. (An example is question #8 on the May 1999 Mathematics HL exam, Paper 1, whose correct answer, $4/5$, can be obtained by the most obvious wrong method—confusing $P(A|S)$, which is given, with $P(S|A)$, which is the answer.)

Finding: The problems on the AP and IB assessments are too predictable. This encourages teachers to focus on helping students recognize and solve particular problem types. A less predictable examination would encourage instruction focused on the development of students' critical thinking and problem-solving abilities.

Finding: Both AP and IB examinations lack good applications and connections to the real-world uses of mathematics. The IB examinations are weaker than the AP examinations in this regard.

4

Teacher Preparation and Professional Development

The College Board publishes teachers' guides and sponsors professional development activities for new and experienced teachers; however, it does not specify in its program materials the instructional strategies to be used by teachers. The International Baccalaureate (IB) mathematics program guides provide general guidance on instruction and also offer specific suggestions about instructional strategies. Teaching notes for each topic in the syllabus for each mathematics course provide suggestions for teachers while stating "it is not mandatory that these suggestions be followed" (International Baccalaureate Organisation [IBO], 1997, p. 8). The teaching notes also include suggestions for linking content to help students see connections, such as linking the study of the second derivative in the Further Calculus option to the study of exponents and logarithms in the core content (IBO, 1997, p. 23).

Neither program describes the professional qualifications required for teachers of its courses, nor do they provide guidance to schools and districts about the level of instructional resources that should be made available to teachers of advanced mathematics. Such resources include, for example, technology, class time, time for collaborative planning and reflection on professional practice, and opportunities for professional development (see below). The panel notes that this lack of specificity is intentional on the part of the IBO. Because IB is an international program offered in many countries with varying resources, the IBO prefers to let schools determine what resources they can make available in the context of their unique situations. The IBO believes specifying necessary resources would create an insurmountable barrier for schools in poor nations or in poor school districts wishing to offer IB. As part of the process used to authorize schools to offer

IB, the IBO ascertains what resources the schools have and how they will be used to offer a quality program.²¹

Both the Advanced Placement (AP) and IB mathematics programs are expanding rapidly, and there is little reason to expect this growth to taper off in the near future. A natural consequence of this growth is an increased demand for well-qualified and well-prepared teachers to staff AP and IB mathematics classrooms. This increased demand comes at a time when there is already a shortage of qualified teachers who are prepared to teach advanced mathematics—a shortage that will be exacerbated by the large number of retirements expected during the next 10 years and a growing turnover rate among U.S. mathematics teachers. The teacher shortage is particularly notable in rural and inner-city schools (National Commission on Mathematics and Science Teaching for the 21st Century, 2000). Current professional development models will be insufficient to ensure adequate numbers of well-prepared and well-qualified AP and IB teachers.

This panel is united in asserting that professional development for teachers of mathematics, as for all teachers, must be a planned, collaborative, ongoing, and relevant process. It is not sufficient to offer one-time workshops, regardless of their length, nor is it prudent to assume that good teachers do not need ongoing support from professional communities. Burton et al. (2000) report that many AP teachers feel isolated and unsupported after leaving AP workshops and returning to their home school districts. AP and IB teachers need opportunities to experiment with new ideas about teaching and learning and to receive feedback about their teaching. Of paramount importance is the need for time to reflect on teaching and learning, both individually and with colleagues.

We draw support for these observations from the work of Liping Ma, a mathematics educator, whose 1999 book *Knowing and Teaching Elementary Mathematics: Teachers' Understanding of Fundamental Mathematics in China and the United States*, sheds light on ways in which professional development for U.S. mathematics teachers can be improved. According to Ma, teachers in China report that their profound understanding of fundamental mathematics was often developed after becoming teachers. The main factors that contribute to Chinese teachers' development of their profound understanding of fundamental mathematics include the following:

- Learning from colleagues
- Learning mathematics from their students

²¹The process of becoming an IB school can take 2 years or more as the IBO evaluates the ability of both the school and the school district to commit resources to providing the administrative structure, faculty, and facilities needed to support offering the IB Diploma programme.

- Learning mathematics by doing problems
- Teaching round-by-round (teaching grades 1–6, or 1–3, 4–5, which develops an understanding of how mathematical concepts build upon each other through the grades)
- Studying teaching materials intensively

Other important differences between U.S. and Chinese teachers include the following:

- Chinese teachers spend more time preparing than teaching a lesson.
- Chinese teachers are organized into “teaching research groups.”
- Chinese teachers learn a great deal of mathematics from their colleagues. They are assigned mentors, with whom they have regular conversations about mathematics.

Teaching materials used by Chinese teachers generally consist of a framework, manuals, and a text. The framework outlines the concepts to be taught, and the manual provides the mathematics background for the corresponding textbook. The manual contains a section-by-section discussion of each topic in the textbook, focusing on the following:

- What is the concept connected with the topic?
- What are the important points in teaching the topic?
- What are the difficult points in teaching the topic?

With Ma’s work in mind, the panel encourages the College Board, the IBO, and individual schools and school districts that offer AP and IB courses to plan, support, and provide professional development activities for AP and IB mathematics teachers that focus on increasing teachers’ subject matter knowledge, knowledge of how students learn mathematics, discipline-specific pedagogical knowledge, mastery of new topics or new approaches to the AP or IB syllabi, opportunities to generate and contribute new knowledge to the profession, and access to collegial communities of AP/IB teachers and to opportunities for collaborative work with college faculty.

AP and IB calculus teachers are often the best in their schools, and many compare favorably with teachers at any level. However, AP and IB teachers still need ongoing opportunities and incentives for professional development both to promote their understanding of the underlying mathematical content and to provide information about exemplary strategies for teaching the courses. These support systems might take one or more of the forms discussed below.

Workshops Prior to Teaching AB/IB. Both AP and IB teachers are offered optional workshops before beginning to teach an AP or IB course,

as well as workshops that cover advanced topics for more experienced teachers.^{22,23} However, a review of selected workshop materials suggests that some of these workshops may be as much administrative as mathematical in nature. The panel's vision for an effective workshop is a format in which teachers are provided an opportunity to deepen their understanding of mathematics, as well as develop their pedagogical expertise.

Teachers' Manuals/Background Information. The College Board and the IBO publish and distribute teachers' manuals (Kennedy, 1997; IBO, 1998b, 1998c, 1998d). However, the panel does not find these materials to be optimally designed to promote the type of instruction emphasized in this report. The panel recommends that manuals be produced in collaboration with high school AP and IB teachers, mathematicians, and mathematics education researchers. The documents should be organized around major mathematical ideas of the AP and IB mathematics courses. We recommend that these manuals include sample questions and answers; text on the mathematical context in which a mathematical idea is situated; and the theoretical underpinnings, the common student misconceptions, and the process by which students acquire understanding. (Note that a new AP Calculus Teachers' Guide was released in 2000, but the panel did not have the opportunity to review it.)

Mentoring Support: Colleagues and the Internet. An essential ingredient in ongoing teacher development is helping every teacher become part of a comfortable and reliable support group. Teachers, especially novice teachers, need a way to have their questions answered. They must feel comfortable sharing their inexperience with content and pedagogy with colleagues who can offer solutions and support. The best support group is usually departmental colleagues, but teachers of calculus are often the only

²²The IB North America Regional Office is responsible for conducting professional development activities for IB teachers during summer week-long workshops, 3–5 day sessions during the school year, and regional conferences. IB workshops focus on some issues that are not part of AP workshops, including attention to restructuring of the ninth- and tenth-grade curriculum at IB schools, the nature of the IB student, and the use of international examples and illustrations in the curriculum. Most mathematics workshops include time spent preparing teachers to teach an unfamiliar and expanded mathematics curriculum, including working on vectors and matrices, probability and statistics, and the optional topics (statistics, abstract algebra, and further geometry).

²³Experienced teachers, university faculty, and College Board staff conduct AP workshops. Currently, the College Board exercises little oversight over these workshops other than to list them on its Web site. The College Board intends to take a more active role in the development and implementation of high-quality professional development activities (Commission on the Future of the Advanced Placement Program, 2001).

members of their departments who are assigned to teach this subject. Additionally, new teachers often express trepidation about professing their ignorance or inexperience regarding either mathematical content or pedagogical strategies for fear that doing so may compromise their academic position in the school or their assignment as an AP or IB teacher. When school colleagues cannot provide appropriate support, district or regional professional groups are an alternative. The College Board, through its regional offices, and the IBO are uniquely positioned to take a leadership role in helping to develop and support these professional communities of teachers.

In recent years, teachers have found an alternative on the Internet. The AP calculus and AP Statistics discussion groups on the Swarthmore College Web site have been highly successful in supporting beginning teachers. The online discussions have helped teachers deepen their understanding of the course content and improve their instructional techniques, particularly with regard to technology.²⁴

In both discussion groups, more experienced high school teachers offer new teachers suggestions for instruction, help clarify content issues, and suggest references and resources to improve instruction. In addition to secondary teachers helping each other, the discussion groups have regular contributions from university faculty. The AP statistics discussion group is characterized by high-level support offered to high school teachers by leading statisticians. For example, the last two presidents of the American Statistical Association regularly offer background information at a fairly deep level to teachers on the topics in the AP curricula. Their responses to teachers' questions reveal an understanding and recognition of both the teachers' level of understanding of the content and the difficulties of teaching statistics. Some panel members note that this level of supportive response is not always true of the AP calculus discussion group. Some teachers who teach both statistics and calculus suggest that while they feel very comfortable asking questions in the statistics group, they hesitate to ask questions in the calculus group. This is the case in part because university mathematicians who participate in the discussions sometimes provide abrupt and condescending responses to questions. It is not uncommon for teachers to feel denigrated by the response, which ends their participation in the discussion.

School-Based Support for Teachers of Advanced High School Mathematics. Instruction for advanced students can be greatly improved by a coordinated effort among the staff teaching at all levels at a school. At a minimum, staff development is needed for precalculus and calculus teach-

²⁴The Swarthmore Web site is The Math Forum, <http://forum.swarthmore.edu> [4/23/02]. Both the College Board and the IBO also sponsor online discussion groups for mathematics teachers.

ers. To address the development of mathematical stamina and persistence in students, staff development should include all teachers, from algebra to calculus.

Part of staff development involves providing a stronger foundation in content knowledge for all teachers. All mathematics teachers need to understand calculus so that students can begin working on its underpinnings in algebra. More important, however, staff development involves ongoing professional contact among colleagues at a school. School districts need to create working environments in which teachers have time to meet and discuss, reflect on, and refine instructional practices. School districts should also create mechanisms for teachers to participate in more structured professional development during contract hours. Currently, most teachers are required to participate in these activities, such as AP or IB teacher workshops, before or after school or during the summer, as suitable substitute teachers are not always available or affordable.

The need for more on-site staff development is particularly acute in schools that offer AP. The AP examinations help focus instruction but because they are so effective the materials that are not on the tests tend not to get taught in the prerequisite courses. These courses generally contain both students who eventually take AP calculus and those who do not. Thus, accommodations are made in prerequisite courses to ensure that all students are prepared to some extent for AP calculus. The AP calculus examinations have therefore become a 3-hour test that measures 5 years of instruction. To the extent that the test is superficial the previous 5 years of instruction will also be superficial. Staff development opportunities are needed for the staff to reclaim some ownership of the instructional output at a school.

Finding: Neither the College Board nor the IBO explicitly articulates in its published materials what it considers to be excellent teaching in mathematics.

Finding: The availability of high-quality professional development activities and the establishment of support networks for AP and IB mathematics teachers are crucial to promoting and maintaining excellence in these programs.

Finding: Adequate preparation of teachers for courses leading to calculus or other advanced study options is a critical factor in enabling students to succeed in the advanced courses.

Finding: U.S. teachers have few opportunities to deepen their understanding of mathematics during the school year, and opportunities during the summer, while useful, tend to be disconnected from everyday teaching.

5

Impact of the AP and IB Programs

Enrollment in Advanced Placement (AP) mathematics courses in the United States far outstrips enrollment in International Baccalaureate (IB) mathematics courses at all levels (see Table 5-1). Consequently, AP calculus has had and continues to exert a far greater influence than the IB courses on the secondary and collegiate mathematics courses offered in the United States. We therefore focus here on the impact of AP.

AP'S IMPACT ON MATHEMATICS IN GRADES 8–12

For most students, goals such as proficiency in problem solving, proof, and application may be more important than calculus. But realizing these goals takes time—time that is not available in a rushed curriculum. As we focus on the AP program and make suggestions for its improvement, we also must ask whether those suggestions will improve mathematics for all. On balance, the effect of AP calculus is probably to improve student achievement in mathematics. However, this is not the case for all students.

Because calculus requires 4 years of preparation, the AP calculus program has repercussions throughout the high school mathematics curriculum and even into the middle-school curriculum. Thus, the question of impact may be more important in mathematics than in the sciences. In some schools, the emphasis on preparing a classroom of students for AP calculus governs the curriculum for all other students. This impact has both positive and negative aspects. On the positive side, calculus helps counteract pressures to make high school mathematics easier. For example, such pressures have led to efforts by some programs to get more students to continue in mathematics by making Algebra II a less challenging course. The need to get students ready for the AP courses helps counter such pressures.

On the negative side, precalculus courses are condensed in some schools so that three semesters can be set aside to cover AP calculus (especially if the school plans to offer AP Calculus BC). This practice may send otherwise

TABLE 5-1 Comparison of Participation in AP and IB Mathematics Courses Based on Number of Examinations Administered

	AP Calculus AB	AP Calculus BC	AP Statistics	IB Mathematical Methods SL	IB Mathematics HL	IB Further Mathematics SL
Number of Examinations in 2000	137,276	34,142	34,118	4,068	1,112	16

NOTES: SL, Standard Level; HL, Higher Level.

strong students to college with an inadequate background in algebra and trigonometry, which they will need for the study of science and engineering, as well as further mathematics. In addition, to complete 4 full years of mathematics prior to enrolling in AP calculus, students must either take a mathematics course over the summer or start algebra in grade 8.²⁵ In the United States, few students take algebra before the ninth grade.²⁶ Thus, the desire to have as many students as possible ready to take calculus by their senior year can lead to condensing the mathematics sequence in a fashion that creates long-term problems for some students. For example, students may choose to “double up” and take two mathematics courses in one year—usually geometry and Algebra II. Other students elect to go to summer school to learn geometry or Algebra II. Because they are compressed, summer courses often do not provide a solid background upon which to build higher-level concepts. High school teachers are aware of the dangers of shortchanging precalculus but are often powerless to resist the pressure from students and parents who believe that calculus on students’ transcripts will boost their chances for admission to college.

The idea that a large proportion of high school students should reach the level of calculus has led to many schools offering, and a significant number of students taking, non-AP and non-IB calculus courses—calculus

²⁵The panel notes that students taking algebra in grade 8 are sometimes taught by teachers who are not certified to teach mathematics. This practice can lead to having students in calculus courses lacking the necessary algebra skills for successful calculus learning. The 1999 Science and Mathematics Indicators (Council of Chief State School Officers [CCSSO], 1999) reveal that 72 percent of middle-school mathematics teachers were certified in mathematics (up 18 percent from 1994).

²⁶According to the State Indicators of Science and Mathematics Education (CCSSO, 1999), only 18 percent of all seventh- and eighth-grade students in the United States were enrolled in Algebra I while in middle school. Another 25 percent took algebra in grade 9.

that is not at the college level.²⁷ Many of these students also lack the necessary algebra and precalculus skills for successful calculus learning. Thus, students in these courses, as well as the less-prepared students in AP calculus courses, would be better served by strengthening their precalculus background and starting calculus in college. A solid background in precalculus is an essential tool for later study in the sciences and quantitative social sciences. The panel sees some merit in developing an AP-level precalculus course for these students (the panel notes that many colleges give credit for precalculus courses). Such a course would be more beneficial to these students than taking a less demanding calculus course or taking AP without adequate preparation, as it would help prepare them for the kind of thinking a good calculus course should require. This would be the ideal course in which to hold students accountable for remembering their mathematical knowledge acquired from algebra and applying it to precalculus. It would encourage the development of students' ability to solve more difficult problems. A strong precalculus course would have the effect of reducing the amount of remediation (currently unacceptably large) that goes on in AP calculus and allowing the exploration of more difficult problems within that course.

Finding: The adequacy of the preparation students receive before taking calculus has an effect on whether they can understand calculus or merely do calculus. Without understanding, students cannot apply what they know and do not remember the calculus they have learned.

Finding: Many teachers and schools are under great pressure to compress algebra and trigonometry so they can prepare as many students as possible for calculus. Sometimes students spend too little time mastering the prerequisite knowledge and skills. The performance of many calculus students is undermined by the fact that they do not learn precalculus thoroughly or learn to solve problems and think mathematically. Thus, the rush to calculus may curtail their future options to pursue mathematics, science, and engineering. It is important to realize that it is not the structure or curriculum

²⁷In September 1986, the Mathematical Association of America (MAA) and the National Council of Teachers of Mathematics (NCTM) released a joint statement advocating that calculus courses taken in high school be at the college level, in other words, at the level of AP or IB. The statement was published in *Calculus for a New Century* (Steen, 1988). The MAA/NCTM statement includes the recommendation "that students who enroll in a calculus course in secondary school should have demonstrated mastery of algebra, geometry, trigonometry, and coordinate geometry. This means that students should have at least four full years of mathematical preparation beginning with the first course in algebra." The panel supports this recommendation. The full text of the statement is in Appendix F.

of the AP calculus courses that causes this problem but the way in which the program is used.

Finding: There are not enough checks in the system to ensure that students have the prerequisite algebra, trigonometry, and precalculus skills necessary for success in calculus and courses beyond.

Finding: The courses that precede calculus are often designed to help students make a smooth transition to an AP course. The topics and speed of prerequisite courses are determined by what is needed for AP. Even schools that do not offer AP calculus usually teach from books and curricula that are used in other schools to prepare students for this course. Thus, the AP curriculum influences many more courses and many more students than those who take the AP examinations.

IMPACT OF AP AND IB ON COLLEGE CALCULUS PROGRAMS

Although the intent of AP courses is to give students a head start on college-level work, many students take high school calculus and then repeat calculus in college. This group includes students who score well on the AP assessment but retake the course in college in the hope of receiving an A, students who take the AP course but do not take the examination, and students who take non-AP calculus courses. Although there are no data on the numbers of students in each category, anecdotally the result is college calculus classes in which only a few students have not had some calculus before. Students who have not had any calculus may feel at a disadvantage in this situation, although the data do not always support their concerns. It is interesting to note that many students who have had calculus in high school and repeat the course in college are also at a disadvantage because they do not devote sufficient attention to their college course, perhaps wrongly believing that they know calculus more deeply than they actually do.

ACCEPTANCE OF STUDENTS' AP AND IB TEST RESULTS BY COLLEGES AND UNIVERSITIES

Students' scores on AP calculus examinations are widely accepted by college and university mathematics departments for placement and/or credit. The amount of credit and final placement in advanced courses are dependent on which AP examination a student takes (AB or BC), the score that he/she earns, and the college or university where the student seeks credit or advanced placement. Research conducted by the College Board and others

(see for example, University of California at Los Angeles, 2000) supports accepting scores of 4 or 5 for credit and/or placement. In one study, researchers administered the same calculus problems to AP calculus students who earned a score of 4 or 5 on the AP examination and students who completed a college calculus course. This study revealed that AP students who scored a 4 or 5 on the AP examination performed on these questions as well as or better than most of their college counterparts who received honor grades in the comparable college courses (College Entrance Examination Board [CEEB], 1999a).

The panel agrees with departmental policies that accept scores of 4 or 5 on an AP calculus examination as evidence that students have mastered knowledge and skills equivalent to those presented in an introductory college calculus course. Through legislative mandate, however, some publicly funded colleges are required to award credit or placement for scores of 3, and the panel is not convinced that such scores reflect sufficient mastery of the subject to warrant credit or placement. Students who earn a score of 3 or lower on an AP examination or 5 on an IB examination can present problems for colleges in terms of placement in introductory courses. The panel suggests that credit or placement should be awarded to students who earn a score of 3 on the AP examination on an individual basis and should be supported by additional evidence beyond examination performance.²⁸

Scores earned on IB mathematics examinations are treated similarly to scores earned on AP calculus examinations. It should be noted, however, that the different levels at which IB courses and examinations can be taken and the variety of optional topics that are included in different classrooms add further considerations for awarding of credit and/or placement, as it is more difficult for a university mathematics department to know exactly what an IB student has learned.

The calculus portion of IB Mathematics HL, including the Approximation and Analysis option, is generally considered to be at least the equivalent of AP Calculus BC. The calculus portion of Mathematical Methods SL by itself is less than a full AP Calculus AB course. However, the majority of Mathematical Methods SL teachers in the United States teach a full calculus class that is equivalent to an AB Calculus course, even though this additional material is not required for the IB examination. Students who earn scores of 6 or 7 are usually regarded as having passed the equivalent of a college-level course. The exact course for which credit and further placement are awarded depends on the IB course and examination for which the student submits a score. Since many fewer students take IB than AP, acceptance of the IB score

²⁸The College Board currently is conducting research on the validity of awarding credit or placement for a score of 3. The panel did not have access to any data from that study. Its results should be published within a year.

is often based on analogy with AP, rather than on an evaluation of the particular strengths of the IB course. There is likely to be less topic-by-topic correspondence between IB courses and college courses than is the case for AP because of differences in the ways in which the IB and AP courses have been developed. However, research and experience appear to indicate that students who have been successful in the IB curriculum are as well prepared for further mathematics as those who have taken AP.²⁹

Neither advanced placement nor acceleration is a goal of the IB program. The International Baccalaureate Organisation does not actively encourage colleges and universities to accept IB examination results for college credit and/or advanced placement in upper-level mathematics courses. Rather, the acceptance of these credits resulted through analogy to AP (conference notes, speech by Paul Campbell, Director of Operations, International Baccalaureate North America). Acceptance occurred slowly as parents, teachers, and students, on an individual basis at first, demonstrated to college registrars and mathematics departments that IB courses were equivalent to AP courses in rigor and content. It was this comparison that led to the acceptance of IB examination scores. Thus, understanding the use of IB examination scores for purposes of college credit and placement also requires understanding how AP gained widespread acceptance.

The College Board has done an admirable job in helping to establish and maintain communication between college and high school mathematics faculties so they can stay abreast of each other's interests and concerns. Members of the AP test development committee, which is responsible for the AP calculus program, are drawn from both college and high school faculty. Every year a group of several hundred college and high school faculty meet for a week or more in early June to grade the free-response questions of that year's AP examination. This provides an excellent opportunity for informal exchanges on mathematics and teaching and allows the College Board to monitor the reactions of college and high school faculty, as well as student responses to questions on the examination.³⁰

²⁹We compare the preparation level of good IB students with that of good AP students because college and university faculty have had much more extensive experience with AP calculus than with IB mathematics. The panel is not implying that AP is the standard to be met.

³⁰The College Board views its experiences with the revision of the AP calculus program as a potential model for ways in which to approach the redesign of other AP courses (Breland and Oltman, 2001). A detailed historical perspective on the communications among the College Board, mathematicians, teachers, and professional mathematics organizations that led to the creation of the new AP calculus courses was written by Dan Kennedy of the Baylor School and can be found on the College Board's Web site: www.collegeboard.com [4/23/02].

Finding: Most college and university placement and credit practices that are based on student performance on AP calculus or IB mathematics examinations are reasonable.

UNINTENDED USES OF AP AND IB ENROLLMENT FIGURES AND EXAMINATION RESULTS

The media and others sometimes use AP and IB scores inappropriately as measures of quality for factors that are not related to the intended purposes of the courses or examinations. For example, some members of the media have proposed using the number of AP and IB courses offered in schools as a tool to rate and rank the schools against each other, possibly leading some schools to offer more AP or IB courses than they are able to support adequately with existing resources. Some schools use the results of AP or IB examinations to evaluate teachers, the consequence of which may be to discourage potentially low-scoring students from taking the courses or the examinations. It is not uncommon for selective colleges to view the existence of AP or IB courses on an applicant's transcript as an important part of their evaluation of the student's intellectual and academic motivations. Without any measure of the quality of the student's achievement in such courses,³¹ however, this emphasis on the number of AP or IB courses on a transcript leads many students to enroll in the courses without a commitment to mastering the material. AP and IB enrollments are increasingly used as a policy lever, as a method of raising the standards and expectations for all students. This leads to negative consequences for students for whom advanced courses in general, and AP and IB mathematics in particular, may not be appropriate.

Finding: Data on the number of AP and IB courses offered by schools and the results of the examinations are sometimes used in ways for which they were not intended, thus creating situations that can be detrimental to student learning.

³¹Results of AP examinations taken in the senior year are not available until long after college acceptances have been sent out.

6

Recommendations

PREPARATION OF STUDENTS

1. All calculus taught in high school should be at the college level.
2. All students who enroll in Advanced Placement (AP) calculus should have had at least 4 years of college preparatory mathematics prior to AP calculus. The structure of International Baccalaureate (IB) mathematics courses is different, and this recommendation is not as applicable to them.
3. Strategies must be developed to ensure that students who enroll in calculus have an adequate background in algebra and trigonometry for subsequent work in mathematics and science.

PROFESSIONAL DEVELOPMENT

4. The professional development opportunities available to AP and IB teachers should be improved and expanded.
5. The College Board and the International Baccalaureate Organization should ensure that adequate professional development opportunities are available to all AP and IB teachers.
6. Schools that choose to offer AP and IB programs must find ways to encourage all teachers to take part in professional development, perhaps by providing time during the school day rather than on nights and weekends.
7. The College Board should consider developing procedures to certify AP calculus teachers.

ASSESSMENT

8. The AP and IB examinations should vary more from year to year. If teachers expect that major ideas will be assessed rather than

specific problem types, it is likely that instruction will encourage the development of students' critical thinking and problem-solving abilities. The AP and IB examinations must strike a balance between judging students' conceptual understanding by asking unfamiliar probing questions and alarming teachers and students with a strange and unfamiliar test.

9. Both the AP and IB programs should maintain and increase their focus on conceptual understanding in their assessments.

10. To assess computational and procedural knowledge, students should be asked questions that demonstrate their ability to use these procedures in solving more complex problems.

11. All students enrolled in AP and IB courses ordinarily should take the relevant external examinations as part of the course requirements.³²

12. AP and IB examinations should contain more emphasis on realistic applications, including those in which students have to set up the mathematical model.

³²The panel recognizes that policies must be developed to ensure that students without the financial means to take the tests are not penalized by this requirement. The panel notes that the College Board is investigating ways to increase the numbers of students who take the AP examination at the conclusion of an AP course. For more information, see the report of the Commission on the Future of the Advanced Placement Program, which is available at www.collegeboard.com [4/23/02].

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Appendix A

Charge to the Content Panels from the Parent Committee

Charge to the Parent Committee and Content Panels: The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines.

Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the committee's charge and study questions.

The panels should focus on the following specific issues in advising the committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facili-

tate retrieval and application in new contexts (see, e.g., National Research Council [NRC], 2000).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?

2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?

3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of coverage with in-depth study of important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?

4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?

5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?

6. To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:

- a) students' mastery of content knowledge;
- b) students' understanding and application of concepts; and
- c) students' ability to apply what they have learned to other courses and in other situations.

2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience and independent investigation)?
2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The NRC's *National Science Education Standards* and the National Council of Teachers of Mathematics' *Standards 2000* propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?
2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?
3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix B

Biographical Sketches of Mathematics Content Panel Members

Harold Boger is currently a mathematics specialist for District G in the Los Angeles Unified School District. Previously he taught at Crenshaw High School. In addition to teaching AP calculus and AP statistics, he served as the chairman of the mathematics department and taught geometry, algebra with transformations, and the second and third levels of an integrated mathematics program. Mr. Boger's thirteen years of outstanding teaching led to his selection as a visiting lecturer at the University of California at Los Angeles as part of the prestigious Visiting High School Teacher Program. He received his B.S. in Applied Mathematics and M.A.Ed. from the University of California at Los Angeles.

Marilyn P. Carlson is an associate professor in the department of mathematics at Arizona State University. Her research area is mathematics education with primary area of focus on cognitive aspects of knowing and learning major conceptual strands of first semester calculus. A National Science Foundation (NSF) CAREER Award is supporting her current development of concept assessment instruments for precalculus and beginning calculus and curricular materials for first semester calculus. She has recently been involved in developing two new Ph.D. programs in research in undergraduate mathematics education at Arizona State University. She is the coordinator for the MAA Special Interest Group, Research in Undergraduate Mathematics Education, and has been active in various professional organizations, including PME, PME-NA, National Council of Teachers of Mathematics (NCTM), Mathematical Association of America (MAA) and Association for Research in Undergraduate Mathematics Education (ARUME). Dr. Carlson received her Ph.D. in mathematics education from the University of Kansas.

Roger E. Howe has been a professor of mathematics at Yale University for over twenty-five years. He has been a visiting scholar at numerous universities, both in the United States and abroad. Recently, Dr. Howe was a Phi Beta Kappa visiting scholar. Dr. Howe is a member of the American Mathematical

Society (AMS), MAA, NCTM, the Connecticut Academy of Science and Engineering, the American Academy of Arts and Sciences, and the National Academy of Sciences (NAS). He is a former member of the Mathematical Sciences Education Board (MSEB). He serves on the board of directors of the Connecticut Academy for Education in Mathematics, Sciences and Technology, and was chairman of the AMS Review Group for revision of the NCTM Standards. He currently serves as chair of the AMS Committee on Education. Dr. Howe received his Ph.D. in mathematics from the University of California at Berkeley.

Daniel J. Teague teaches mathematics at The North Carolina School of Science and Mathematics in Durham, North Carolina. His twenty-five years of teaching at both the secondary and undergraduate levels have been recognized by awards such as the Tandy Technology Scholar Outstanding Teacher Award and the Presidential Award for Excellence in Mathematics Teaching. Dr. Teague's previous National Research Council (NRC) experience includes appointments to the MSEB and the U.S. Commission on Mathematics Instruction. He received his Ph.D. in Mathematics Education from North Carolina State University where he completed his doctoral work in international comparisons of calculus education.

Alan C. Tucker is a professor with the Department of Applied Mathematics and Statistics at the State University of New York at Stony Brook. He has served the department for over 30 years, previously as the department chair and currently as associate department chair and undergraduate program director. Dr. Tucker currently heads the NSF-funded Long Island Consortium for Interconnected Learning, which explores the teaching and learning of mathematically based subjects through instruction, curricula, technology, and interdepartmental coordination. He has previously served the NRC with appointments to MSEB's Undergraduate Math Advisory Board and the U.S. Commission on Mathematics Instruction. Dr. Tucker received his Ph.D. in Mathematics from Stanford University.

Deborah Hughes Hallett (committee liaison and chair) is a professor of mathematics at the University of Arizona; from 1991 to 1998 she was a Professor of Practice in the Teaching of Mathematics at Harvard University. She was a principal investigator for the NSF-funded Bridge Calculus Consortium. She has served on committees for the Graduate Record Examination and the Massachusetts state mathematics framework review process, and on the Mathematics and Science Teacher Education Program (MASTEP) Advisory Board, an NSF-funded program to improve teacher training in California. Dr. Hughes Hallett served on NRC's Committee on Information Technology in Undergraduate Education. A Fulbright Scholar, she received M.A. degrees from both Harvard University and the University of Cambridge, England.

Appendix C

Topical Outline for AP Calculus AB

This outline of topics is intended to indicate the scope of the course, but it is not necessarily the order in which the topics are to be taught. Teachers may find that topics are best taught in different orders. (See the *Teacher's Guide—AP Calculus* [Kennedy, 1997] for sample syllabi.) Although the examination is based on the topics listed in the topical outline, teachers may wish to enrich their courses with additional topics.

I. Functions, Graphs, and Limits

Analysis of graphs. With the aid of technology, graphs of functions are often easy to produce. The emphasis is on the interplay between the geometric and analytic information and on the use of calculus both to predict and to explain the observed local and global behavior of a function.

Limits of functions (including one-sided limits).

- An intuitive understanding of the limiting process.
- Calculating limits using algebra.
- Estimating limits from graphs or tables of data.

Asymptotic and unbounded behavior.

- Understanding asymptotes in terms of graphical behavior.
- Describing asymptotic behavior in terms of limits involving infinity.
- Comparing relative magnitudes of functions and their rates of change.

(For example, contrasting exponential growth, polynomial growth, and logarithmic growth.)

Continuity as a property of functions.

- An intuitive understanding of continuity. (Close values of the domain lead to close values of the range.)

- Understanding continuity in terms of limits.
- Geometric understanding of graphs of continuous functions (Intermediate Value Theorem and Extreme Value Theorem).

II. Derivatives

Concept of the derivative.

- Derivative presented graphically, numerically, and analytically.
- Derivative interpreted as an instantaneous rate of change.
- Derivative defined as the limit of the difference quotient.
- Relationship between differentiability and continuity.

Derivative at a point.

- Slope of a curve at a point. Examples are emphasized, including points at which there are vertical tangents and points at which there are no tangents.
- Tangent line to a curve at a point and local linear approximation.
- Instantaneous rate of change as the limit of average rate of change.
- Approximate rate of change from graphs and tables of values.

Derivative as a function.

- Corresponding characteristics of graphs of f and f' .
- Relationship between the increasing and decreasing behavior of f and the sign of f' .
- The Mean Value Theorem and its geometric consequences.
- Equations involving derivatives. Verbal descriptions are translated into equations involving derivatives and vice versa.

Second derivatives.

- Corresponding characteristics of the graphs of f , f' , and f'' .
- Relationship between the concavity of f and the sign of f'' .
- Points of inflection as places where concavity changes.

Applications of derivatives.

- Analysis of curves, including the notions of monotonicity and concavity.
- Optimization, both absolute (global) and relative (local) extrema.
- Modeling rates of change, including related rates problems.
- Use of implicit differentiation to find the derivative of an inverse function.
- Interpretation of the derivative as a rate of change in varied applied contexts, including velocity, speed, and acceleration.

Computation of derivatives.

- Knowledge of derivatives of basic functions, including power, exponential, logarithmic, trigonometric, and inverse trigonometric functions.
- Basic rules for the derivative of sums, products, and quotients of functions.
- Chain rule and implicit differentiation.

III. Integrals

Interpretations and properties of definite integrals.

- Computation of Riemann sums using left, right, and midpoint evaluation points.
- Definite integral as a limit of Riemann sums over equal subdivisions.
- Definite integral of the rate of change of a quantity over an interval interpreted as the change of the quantity over the interval:

$$\int_a^b f'(x)dx = f(b) - f(a)$$

- Basic properties of definite integrals. (Examples include additivity and linearity.)

Applications of integrals. Appropriate integrals are used in a variety of applications to model physical, social, or economic situations. Although only a sampling of applications can be included in any specific course, students should be able to adapt their knowledge and techniques to solve other similar application problems. Whatever applications are chosen, the emphasis is on using the integral of a rate of change to give accumulated change or using the method of setting up an approximating Riemann sum and representing its limit as a definite integral. To provide a common foundation, specific applications should include finding the area of a region, the volume of a solid with known cross sections, the average value of a function, and the distance traveled by a particle along a line.

Fundamental theorem of calculus.

- Use of the Fundamental Theorem to evaluate definite integrals.
- Use of the Fundamental Theorem to represent a particular antiderivative, and the analytical and graphical analysis of functions so defined.

Techniques of antidifferentiation.

- Antiderivatives following directly from derivatives of basic functions.
- Antiderivatives by substitution of variables (including change of limits for definite integrals).

Applications of antidifferentiation.

- Finding specific antiderivatives using initial conditions, including applications to motion along a line.
- Solving separable differential equations and using them in modeling. In particular, studying the equation $y' = ky$ and exponential growth.

Numerical approximations to definite integrals. Use of Riemann and trapezoidal sums to approximate definite integrals of functions represented algebraically, geometrically, and by tables of values.

SOURCE: College Entrance Examination Board (1999, pp. 6–9).

Appendix D

Topical Outline for AP Calculus BC

The topic outline for Calculus BC includes all Calculus AB topics. Additional topics are found in paragraphs that are marked with a plus sign (+) or an asterisk (*). The additional topics can be taught anywhere in the course that the instructor wishes. Some topics will naturally fit immediately after their Calculus AB counterparts. Other topics may fit best after the completion of the Calculus AB topical outline. (See the *Teacher's Guide—AP Calculus* [Kennedy, 1997] for sample syllabi.) Although the examination is based on the topics listed in the topical outline, teachers may wish to enrich their courses with additional topics.

I. Functions, Graphs, and Limits

Analysis of graphs. With the aid of technology, graphs of functions are often easy to produce. The emphasis is on the interplay between the geometric and analytic information and on the use of calculus both to predict and to explain the observed local and global behavior of a function.

Limits of functions (including one-sided limits).

- An intuitive understanding of the limiting process.
- Calculating limits using algebra.
- Estimating limits from graphs or tables of data.

Asymptotic and unbounded behavior.

- Understanding asymptotes in terms of graphical behavior.
- Describing asymptotic behavior in terms of limits involving infinity.
- Comparing relative magnitudes of functions and their rates of change.

(For example, contrasting exponential growth, polynomial growth, and logarithmic growth.)

Continuity as a property of functions.

- An intuitive understanding of continuity. (Close values of the domain lead to close values of the range.)
- Understanding continuity in terms of limits.
- Geometric understanding of graphs of continuous functions (Intermediate Value Theorem and Extreme Value Theorem).

***Parametric, polar, and vector functions.** The analysis of planar curves includes those given in parametric form, polar form, and vector form.

II. Derivatives

Concept of the derivative.

- Derivative presented geometrically, numerically, and analytically.
- Derivative interpreted as an instantaneous rate of change.
- Derivative defined as the limit of the difference quotient.
- Relationship between differentiability and continuity.

Derivative at a point.

- Slope of a curve at a point. Examples are emphasized, including points at which there are vertical tangents and points at which there are no tangents.
- Tangent line to a curve at a point and local linear approximation.
- Instantaneous rate of change as the limit of average rate of change.
- Approximate rate of change from graphs and tables of values.

Derivative as a function.

- Corresponding characteristics of graphs of f and f' .
- Relationship between the increasing and decreasing behavior of f and the sign of f' .
- The Mean Value Theorem and its geometric consequences.
- Equations involving derivatives. Verbal descriptions are translated into equations involving derivatives and vice versa.

Second derivatives.

- Corresponding characteristics of the graphs of f , f' , and f'' .
- Relationship between the concavity of f and the sign of f'' .
- Points of inflection as places where concavity changes.

Applications of derivatives.

- Analysis of curves, including the notions of monotonicity and concavity.

- + Analysis of planar curves given in parametric form, polar form, and vector form, including velocity and acceleration vectors.
 - Optimization, both absolute (global) and relative (local) extrema.
 - Modeling rates of change, including related rates problems.
 - Use of implicit differentiation to find the derivative of an inverse function.
 - Interpretation of the derivative as a rate of change in varied applied contexts, including velocity, speed, and acceleration.
- + Geometric interpretation of differential equations via slope fields and the relationship between slope fields and derivatives of implicitly defined functions.
 - + Numerical solution of differential equations using Euler's method.
 - + L'Hôpital's Rule and its use in determining convergence of improper integrals and series.

Computation of derivatives.

- Knowledge of derivatives of basic functions, including power, exponential, logarithmic, trigonometric, and inverse trigonometric functions.
- Basic rules for the derivative of sums, products, and quotients of functions.
 - Chain rule and implicit differentiation.
- + Derivatives of parametric, polar, and vector functions.

III. Integrals

Interpretations and properties of definite integrals.

- Computation of Riemann sums using left, right, and midpoint evaluation points.
- Definite integral as a limit of Riemann sums over equal subdivisions.
- Definite integral of the rate of change of a quantity over an interval interpreted as the change of the quantity over the interval:

$$\int_a^b f'(x)dx = f(b) - f(a)$$

- Basic properties of definite integrals. (Examples include additivity and linearity.)

***Applications of integrals.** Appropriate integrals are used in a variety of applications to model physical, social, or economic situations. Although only a sampling of applications can be included in any specific course, students should be able to adapt their knowledge and techniques to solve other similar application problems. Whatever applications are chosen, the emphasis is on using the integral of a rate of change to give accumulated change or

using the method of setting up an approximating Riemann sum and representing its limit as a definite integral. To provide a common foundation, specific applications should include finding the area of a region (including a region bounded by polar curves), the volume of a solid with known cross sections, the average value of a function, the distance traveled by a particle along a line, and the length of a curve (including a curve given in parametric form).

Fundamental theorem of calculus.

- Use of the Fundamental Theorem to evaluate definite integrals.
 - Use of the Fundamental Theorem to represent a particular antiderivative, and the analytical and graphical analysis of functions so defined.
- Techniques of antidifferentiation.
- Antiderivatives following directly from derivatives of basic functions.
 - + Antiderivatives by substitution of variables (including change of limits for definite integrals), parts, and simple partial fractions (nonrepeating linear factors only).
 - + Improper integrals (as limits of definite integrals).

Applications of antidifferentiation.

- Finding specific antiderivatives using initial conditions, including applications to motion along a line.
 - Solving separable differential equations and using them in modeling.
- In particular, studying the equation $y' = ky$ and exponential growth.
- + Solving logistic differential equations and using them in modeling.

Numerical approximations to definite integrals. Use of Riemann and trapezoidal sums to approximate definite integrals of functions represented algebraically, geometrically, and by tables of values.

***IV. Polynomial Approximations and Series**

***Concept of series.** A series is defined as a sequence of partial sums, and convergence is defined in terms of the limit of the sequence of partial sums. Technology can be used to explore convergence or divergence.

***Series of constants.**

- + Motivating examples, including decimal expansion.
- + Geometric series with applications.
- + The harmonic series.
- + Alternating series with error bound.

- + Terms of series as areas of rectangles and their relationship to improper integrals, including the integral test and its use in testing the convergence of p -series.

- + The ratio test for convergence and divergence.
- + Comparing series to test for convergence or divergence.

***Taylor series.**

- + Taylor polynomial approximation with graphical demonstration of convergence. (For example, viewing graphs of various Taylor polynomials of the sine function approximating the sine curve.)

- + Maclaurin series and the general Taylor series centered at $x = a$.

- + Maclaurin series for the functions e^x , $\sin x$, $\cos x$, and $1 / (1 - x)$.

- + Formal manipulation of Taylor series and shortcuts to computing Taylor series, including substitution, differentiation, antidifferentiation, and the formation of new series from known series.

- + Functions defined by power series.

- + Radius and interval of convergence of power series.

- + Lagrange error bound for Taylor polynomials.

SOURCE: College Entrance Examination Board (1999a, 1999c, pp. 9–14).

Appendix E

Syllabus Details, IB Mathematics HL, Core Calculus Material

SOURCE: International Baccalaureate Organisation (1998a, 1998c).

8 Core: Calculus

Teaching time: 50 hours

The aim of this section is: to introduce the basic concepts and techniques of differential and integral calculus, and some of their applications.

CONTENT	APPLICATIONS/EXCLUSIONS	TEACHING NOTES
<p>8.1 Informal ideas of a limit and convergence. The result $\lim_{\theta \rightarrow 0} \frac{\sin \theta}{\theta} = 1$ justified by geometric demonstration.</p>	<p>Included: only a very informal treatment of limit and convergence, e.g. 0.3, 0.33, 0.333, ... converges to $\frac{1}{3}$.</p>	<p>Link with infinite geometric series in §1.1. Link with the binomial theorem in §1.3. Calculators can be used to investigate limits numerically.</p>
<p>8.2 Differentiation from first principles as the limit of the difference quotient $f'(x) = \lim_{h \rightarrow 0} \left(\frac{f(x+h) - f(x)}{h} \right)$ Differentiation of: $x \mapsto x^n, n \in \mathbb{Q}$; $x \mapsto \sin x$; $x \mapsto \cos x$; $x \mapsto \tan x$; $x \mapsto e^x$; $x \mapsto \ln x$.</p>	<p>Included: a formal treatment for positive integer powers; informal extension to rational powers; a formal treatment for $x \mapsto \sin x$. Included: familiarity with the notation $y = f(x) \Rightarrow \frac{dy}{dx} = f'(x).$</p>	<p>Other derivatives can be predicted or verified by graphical considerations using graphic display calculator. Investigation of the derivative of x^n from consideration of the function $\frac{(x+h)^n - x^n}{h}$ and its graph, for small h, $n \in \mathbb{Z}^+$ can enhance understanding of limits.</p>
<p>8.3 Differentiation of sums of functions and real multiples of functions. The chain rule for composite functions.</p>	<p>Included: derivatives of reciprocal trigonometric functions $x \mapsto \sec x$, $x \mapsto \csc x$, $x \mapsto \cot x$. Included: applications to rates of change.</p>	<p>Link with composite functions in §2.1. Link with implicit differentiation in §8.7. Link with integration by parts in §8.10.</p>
<p>8.4 Further differentiation: the product and quotient rules; the second derivative; differentiation of a^x and $\log_a x$.</p>	<p>Included: understanding that $2^x = e^{x \ln 2}$, etc.</p>	

8 Core: Calculus (continued)

CONTENT	AMPLIFICATIONS/EXCLUSIONS	TEACHING NOTES
<p>8.5 Graphical behaviour of functions: tangents, normals and singularities, behaviour for large x; asymptotes. The significance of the second derivative; distinction between maximum and minimum points and points of inflexion.</p>	<p>Included: both 'global' and 'local' behaviour; choice of appropriate window; (a, b) point of inflexion $\Rightarrow f''(a) = 0$, but the converse is not necessarily true; points of inflexion with zero or non-zero gradient.</p>	<p>Effective use of graphic display calculator envisaged here, combined with sketching by hand. Link with function graphing skills in §2.2. The terms 'concave-up' and 'concave-down' conveniently distinguish between $f''(x) > 0$ and $f''(x) < 0$ respectively. Link with graphing functions in §2.2.</p>
<p>8.6 Applications of the first and second derivative to maximum and minimum problems. Kinematic problems involving displacement, s, velocity, $\frac{ds}{dt} = v$, and acceleration, $\frac{dv}{dt} = a$.</p>	<p>Included: testing for maximum or minimum (e.g. volume, area and profit) using the sign of the first derivative or using the second derivative.</p>	<p>Link with chain rule in §8.3.</p>
<p>8.7 Implicit differentiation. Derivatives of the inverse trigonometric functions.</p>	<p>Included: applications to related rates of change. Not required: second derivatives of parametric functions.</p>	<p>Candidates could be made aware of the fundamental theorem of calculus, $F(x) = \int_a^x f(t) dt \Rightarrow F'(x) = f(x)$, and discuss its graphical interpretation.</p>
<p>8.8 Indefinite integration as anti-differentiation. Indefinite integrals of: x^n; $n \in \mathbb{Q}$, $\sin x$; $\cos x$; e^x. Composites of these with $x \mapsto ax + b$. Application to acceleration and velocity.</p>	<p>Example: $f'(x) = \cos(2x + 3)$ $\Rightarrow f(x) = \frac{1}{2} \sin(2x + 3) + C$.</p>	

8 Core: Calculus (continued)

CONTENT	APPLICATIONS/EXCLUSIONS	TEACHING NOTES
<p>8.9 Anti-differentiation with a boundary condition to determine the constant term. Definite integrals. Areas under curves.</p>	<p>Example of a boundary condition: if $\frac{ds}{dt} = 3t^2 + t$, and $s = 10$ when $t = 0$, then $s = t^3 + \frac{1}{2}t^2 + 10$.</p>	<p>Area under velocity-time graph representing distance is a useful illustration.</p>
<p>8.10 Further integration: integration by substitution; integration by parts; definite integrals.</p>	<p>Included: limit changes in definite integrals; questions requiring repeated integration by parts; integrals requiring further manipulation, e.g. $\int e^x \sin x \, dx$; integration using partial fraction decomposition.</p>	<p>Link with transformations of graphs in §2.3. Link with the chain rule in §8.3.</p>
<p>8.11 Solution of first order differential equations by separation of variables.</p>	<p>Included: transformation of a homogeneous equation by the substitution $y = vx$.</p>	<p>Link with exponential and logarithmic functions in §2.10.</p>

Appendix F

Text of a Letter Endorsed by the Governing Boards of the Mathematical Association of America and the National Council of Teachers of Mathematics Concerning Calculus in the Secondary Schools³³

TO: Secondary School Mathematics Teachers
FROM: The Mathematical Association of America
The National Council of Teachers of Mathematics
DATE: September, 1986
RE: Calculus in the Secondary School

Dear Colleague:

A single variable calculus course is now well established in the 12th grade at many secondary schools, and the number of students enrolling is increasing substantially each year. In this letter, we would like to discuss two problems that have emerged.

The first problem concerns the relationship between the calculus course offered in high school and the succeeding calculus courses in college. *The*

³³This letter was extracted from *Calculus for a New Century: A Pump, Not a Filter*, A National Colloquium, October 28–29, 1987 (MAA Notes, Number 8, edited by Lynn Arthur Steen for the Board on Mathematical Sciences and the Mathematical Sciences Education Board of the National Research Council, Mathematical Association of America, 1988).

Mathematical Association of America (MAA) and the National Council of Teachers of Mathematics (NCTM) recommend that the calculus course offered in the 12th grade should be treated as a college-level course. The expectation should be that a substantial majority of the students taking the course will master the material and will not then repeat the subject upon entrance to college. Too many students now view their 12th grade calculus course as an introduction to calculus with the expectation of repeating the material in college. This causes an undesirable attitude on the part of the student both in secondary school and in college. In secondary school all too often a student may feel “I don’t have to study this subject too seriously, because I have already seen most of the ideas.” Such students typically have considerable difficulty later on as they proceed further into the subject matter.

MAA and NCTM recommend that all students taking calculus in secondary school who are performing satisfactorily in the course should expect to place out of the comparable college calculus course. Therefore, to verify appropriate placement upon entrance to college, students should either take one of the Advanced Placement (AP) Calculus Examinations of the College Board, or take a locally-administered college placement examination in calculus. Satisfactory performance on an AP examination carries with it college credit at most universities.

The second problem concerns preparation for the calculus course. *MAA and NCTM recommend that students who enroll in a calculus course in secondary school should have demonstrated mastery of algebra, geometry, trigonometry, and coordinate geometry.* This means that students should have at least four full years of mathematical preparation beginning with the first course in algebra. The advanced topics in algebra, trigonometry, analytic geometry, complex numbers, and elementary functions studied in depth during the fourth year of preparation are critically important for students’ latter courses in mathematics.

It is important to note that at present many well-prepared students take calculus in the 12th grade, place out of the comparable course in college, and do well in succeeding college courses. Currently, the two most common methods for preparing students for a college-level calculus course in the 12th grade are to begin the first algebra course in the 8th grade or to require students to take second year algebra and geometry concurrently. Students beginning with algebra in the 9th grade, who take only one mathematics course each year in secondary school, should not expect to take calculus in the 12th grade. Instead, they should use the 12th grade to prepare themselves fully for calculus as freshmen in college.

We offer these recommendations in an attempt to strengthen the calculus program in secondary schools. They are not meant to discourage the

teaching of college-level calculus in the 12th grade to strongly prepared students.

LYNN ARTHUR STEEN
President, Mathematical Association of America

JOHN A. DOSSEY
President, National Council of Teachers of Mathematics

