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Content Panel Report:

Biology

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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

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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

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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.

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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-

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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

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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*.

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3

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.

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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

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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

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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:

[a]Based 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.

[b]From ETS (1999, pp. 3–5). Percentages of total class time, including laboratory.

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TABLE 3-2 Percentages and Hours of Class Time Spent on Various Subareas of Biology in IB and AP Courses

Total Teaching Time				
% of IB Teaching Time Specified for a Concept (total hours 240)	Prescribed Teaching Hours	IB Curriculum Topics (1:, etc.) That Correspond to AP Concepts	AP Teaching Concepts	% of AP Teaching Time Specified for a Concept (total hours 180)
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[a]	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	(evolution counted above) E: neurobiology/ behavior; F: applied plant/animal science, G: ecology and conservation		0
Total: 75	181			100

continues

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TABLE 3-2 Continued

% of IB Time in Labs (240 hours)	Prescribed Laboratory Hour	B Curriculum Topics (1:, etc.) That Correspond to AP Concepts	Laboratory Program	% od AP Time in Labs (180 hours)
Laboratory				
4	10		Group 4 Interdisciplinary Inquiry Lab Project	0
7	16		Options laboratory work	
14	33	6: investigations (15), 17: investigations (18)	Laboratory Program	12 prescribed labs
Total: 25	59			0[d]

SOURCES: Adapted from IBO (1996), ETS (1999).

[a]From IB optional topics. Note that teaching evolution is an option in the IB program.

[b]Covered under the concept Structure of Plants and Animals, which includes discussion of functions.

[c]IB 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.

[d]Laboratory time not specified (see the discussion later in this chapter).

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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

[1]In 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.

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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

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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

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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	*NSES*[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).

[a]This 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).

[b]Equilibrium is apparently used by the IB program (misleadingly) to mean steady state or homeostasis.

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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).

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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

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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,

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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-

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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

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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.

[2]Based on reports of teachers interviewed and the panel's inspection of recent AP and IB exams.

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- 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.

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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.

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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-

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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-

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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

[3]Based on teacher interviews and review of AP and IB materials by the panel.

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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

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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 *do not* know	Assessing to learn what students *do* 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.

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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.

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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

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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.

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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).

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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.

[4]In 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.

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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-

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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.

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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

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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

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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

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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

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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

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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-

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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.

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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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References

Commission on the Future of the Advanced Placement Program. (2001). *Access to excellence: The report of the Commission on the Future of the Advanced Placement Program*. New York: The College Board.

Educational Testing Service. (1999). *Advanced placement program course description: Biology*. New York: Author.

Hurd, P.D. (1961). *Biology education in American secondary schools*. BSCS Bulletin #1. Baltimore: AIBS/Waverly Press.

International Baccalaureate Organisation. (1996). *International Baccalaureate biology*. Geneva, Switzerland: Author.

Morgan, R., & Ramist, L. (1998). *Advanced placement students in college: An investigation of course grades at 21 colleges*. ETS Report #SR-98-13. New York: Educational Testing Service.

National Commission on Mathematics and Science Teaching for the 21st Century. (2000). *Before it's too late: A report to the nation from the National Commission on Mathematics and Science Teaching for the 21st Century*. Jessup, MD: Education Publications Center.

National Research Council. (1990). *Fulfilling the promise: Biology education in the nation's schools*. Washington, DC: National Academy Press.

National Research Council. (1996a). *National science education standards*. National Committee on Science Education Standards and Assessment, Coordinating Council for Education. Washington, DC: National Academy Press.

National Research Council. (1996b). *The role of scientists in the professional development of science teachers*. Committee on Biology Teacher Inservice Programs. Washington, DC: National Academy Press.

National Research Council. (1999). *How people learn: Brain, mind, experience, and school*. Committee on Developments in the Science of Learning, ed. J.D. Bransford, A.L. Brown, and R.R. Cocking. Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

National Research Council. (2000a). *How people learn: Bridging research and practice*. Committee on Developments in the Science of Learning, ed. J.D. Bransford, A.L. Brown, and R.R. Cocking. Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

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National Research Council. (2000b). *Inquiry and the national science education standards: A guide for teaching and learning*. Center for Science, Mathematics, and Engineering Education. Washington, DC: National Academy Press.
Shenk, D. (1997). *Data smog: Surviving the information glut*. San Francisco: Harper.

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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-

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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?

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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?

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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 31years. She presently works as a consultant to the New York State Education De-

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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 Shaugnessy 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

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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 15º 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.

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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 Placment (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

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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.

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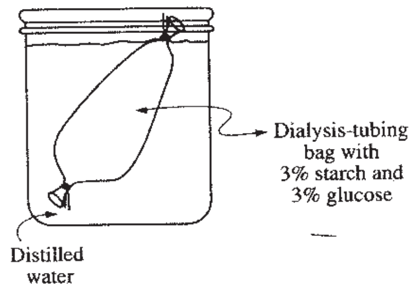

114. From the initial conditions and results described, which of the following is a logical conclusion? (A) The initial concentration of glucose in the bag is higher than the initial concentration of starch in the bag. (B) The pores of the bag are larger than the glucose molecules but smaller than the 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.

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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 mitrochondrion. C. Explain the process of muscle contraction.

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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

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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 (*using a range of appropriate scientific methods/techniques*).
Data analysis	Transformed, manipulated and presented data (*in a variety of appropriate ways*) 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

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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).

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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.bscs.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/

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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

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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-**

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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

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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."**

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