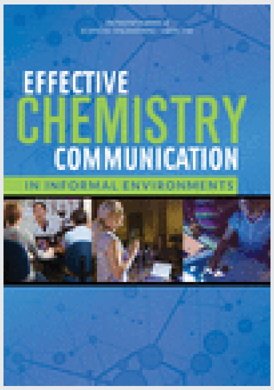

Effective Chemistry Communication in Informal Environments

DETAILS

168 pages | 7 x 10 | PAPERBACK
ISBN 978-0-309-37752-2 | DOI: 10.17226/21790

AUTHORS

Committee on Communicating Chemistry in Informal Settings; Board on Chemical Sciences and Technology; Division on Earth and Life Studies; Board on Science Education; Division of Behavioral and Social Sciences and Education; National Academies of Sciences, Engineering, and Medicine

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

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THE NATIONAL ACADEMIES PRESS
Washington, DC
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This activity was supported by Grant No. 1238273 from the National Science Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13: 978-0-309-37752-2
International Standard Book Number-10: 0-309-37752-8
Library of Congress Control Number: 2016946891
Digital Object Identifier: 10.17226/21790

Additional copies of this report are available for sale from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

Printed in the United States of America

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2016. *Effective Chemistry Communication in Informal Environments*. Washington, DC: The National Academies Press. doi: 10.17226/21790.

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Preface

The committee's report seeks to enhance the effectiveness of public communication by chemists at activities that foster engagement and learning outside the classroom setting. We build on two trends: One is the interest shown by many chemists in sharing their knowledge and experience with the public through activities such as National Chemistry Week, science festivals, museum exhibits or events, science cafés, and online media. The second is the growing research on science communication, informal learning, and chemistry education. Much of that research has been synthesized in previous National Research Council reports, including *Learning Science in Informal Environments, Discipline-Based Education Research*, and *How People Learn*, as well as two Sackler Colloquia on *The Science of Science Communication* and the Chemical Sciences Roundtable's *Chemistry in Primetime and Online*. For the first time, the experiences of these professional communities and the research bases that support their work have been integrated for the development of practical tools.

Chemistry plays critical roles in our daily lives, community issues, national policy, and global events. That everyday relevance presents opportunities for interaction with members of the public who may not be familiar with chemistry or chemical concepts. Evidence-based communication and engagement activities offer the potential to address the situation. For students, informal learning experiences can stimulate greater interest in chemistry, complementing and enhancing the subject as presented within the limitations of the classroom. For adults, such experiences may help them become more sophisticated about chemistry and its ubiquitous role in the world around us.

For the chemistry community, we hope that this report will provide insights for thinking about communication and engagement. It offers guidance based on evidence-based practices for strengthening the effectiveness of activities, such as placing greater focus on the needs and interests of the participants, both in planning and implementation.

For informal learning professionals and science communicators, we hope the report will provide insight from key research findings in the chemical education literature that may be transferable to addressing members of the public and may suggest directions for future research. In addition, this report may encourage more chemists and chemistry-related professionals to partner with science centers and similar organizations to develop and implement engaging chemistry experiences for children and for adults. Such collaborative efforts could be significantly enhanced by support from chemistry-based professional organizations and corporations.

Although this report focuses specifically on chemistry, the communication strategies could be applied more generally and serve as a model for other disciplines. We hope that professionals in those disciplines will recognize the value of applying effective practices of informal learning and science communication, and of partnering with organizations experienced in engaging with the public.

On behalf of the committee, we would like to thank all those who took the time to share their knowledge and expertise through participation in the meetings, the landscape study, and other data-gathering methods. Special thanks go to the committee members themselves and the Academies program staff who made this report possible.

Mark Ratner and David Ucko, *Co-Chairs*

Acknowledgment of Reviewers

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

James Bell, Center for the Advancement of Informal Science Education
John Besley, Michigan State University
Donna Blackmond, Scripps University
Rick Borchelt, U.S. Department of Energy
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Tiffany Lohwater, American Association for the Advancement of Science
Stephen Palacios, Added Value Cheskin
Elsa Reichmanis, Georgia Institute of Technology
Nancy Songer, Drexel University
Lawrence Yeung, Rice University

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before the release. The review of this report was overseen

by **May Berenbaum,** University of Illinois at Urbana-Champaign, and **R. Stephen Berry,** University of Chicago. They were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Summary

In response to a request from the National Science Foundation, the National Academies of Sciences, Engineering, and Medicine (the Academies) convened an ad hoc committee to characterize current efforts at communicating chemistry, to synthesize existing social science research on effective communication, and to develop a framework that lays out evidence-based strategies to design chemistry communication activities. Part A of this report provides the framework, as well as a synthesis of the research (drawn from a variety of social science disciplines) that supports the development of the steps described in the framework. Part B of the report is a guide for chemists titled *Communicating Chemistry: A Framework for Sharing Science*, which is also provided as a separate, stand-alone document. In the guide, the committee summarizes the framework in practical terms to support chemists and organizations working with chemists in creating effective communication and learning activities in settings outside of formal schools. Although this report and the guide focus specifically on chemistry, the communication strategies could be applied more generally and serve as a model for other scientific disciplines.

THE IMPORTANCE OF COMMUNICATING CHEMISTRY NOW

The topic of communicating chemistry is both important and timely. The digital or communication age has dramatically expanded the number of people with access to topics that were once the purview of a few experts. This, among other things, has changed the traditional pact between the scientific community and the public. No longer is scientific research being conducted with little need or opportunity to explain the reason for the research or its results, outside of the science community. In addition, chemistry plays critical roles in people's daily lives, in topics such as energy and its impacts, global climate change, medicine and health, national security, and the environment, and in many of the consumer products that people rely on. Better public understanding of chemistry could lead to improved policy and decision making and to more-informed consumer choices. Finally, the chemistry community is in need of guidance on communicating chemistry to the public. Undergraduate and graduate schools often do not prepare chemists to communicate their work to members of the public, and there are few options for communication training for professional scientists.

THE BASIS OF THIS REPORT

In drafting this document, committee members heard from experts in learning outside of school (often referred to as *informal learning* or *informal education*), science communication across various formats, formal chemistry education, marketing, and evaluation of informal learning. The committee surveyed the growing research on informal learning, science communication, and chemical education. Much of that research has been amalgamated in previous Academies reports, including *Learning Science in Informal Environments* (NRC, 2009), *Discipline-Based Education Research* (NRC, 2012), and *How People Learn* (NRC, 2000), as well as in two Sackler Colloquia on *The Science of Science Communication* and the Chemical Sciences Roundtable's workshop, *Chemistry in Primetime and Online* (NRC, 2011). The committee also commissioned two reports: a landscape study (Grunwald Associates and Education Development Center) that examined the current state of the art with regard to communicating chemistry in informal settings and a white paper on evaluation.

A FRAMEWORK FOR COMMUNICATING CHEMISTRY

Based on the research and a review of effective practices, the committee created a five-element framework, the *Framework for Effective Chemistry Communication*. The framework emphasizes the importance of focusing on the needs and interests of the participants in both planning and implementation. The framework also stresses the importance of evaluation, begun at the outset of communication planning and development, in making communication activities more effective at meeting their intended goals. The five elements of the framework are

Element 1. Set communication goals and outcomes appropriate for the target participants.
Element 2. Familiarize yourself with your resources.
Element 3. Design the communication activity and how it will be evaluated.
Element 4. Communicate!
Element 5. Assess, reflect, and follow up.

The framework is not a one-size-fits-all prescription—judgment must be used to scale activities to the available resources and evaluation capabilities. For example, the framework clearly stresses the importance of evaluation, but the committee recognizes that most chemists are not well versed in evaluation techniques and often may not have the time, resources, or incentives to conduct extensive evaluation of the effectiveness of their activity. For this reason, the report encourages scaling the evaluation as appropriate to the activity and, where extensive evaluation is appropriate, partnering with experts in evaluation. Even simple evaluation can prove valuable.

THE GUIDE

The guide, *Communicating Chemistry: A Framework for Sharing Science*, is intended as a practical aid to chemists in designing effective informal communication activities for non-expert participants. It is based on the committee's five-element framework, and its explanatory text and examples are geared toward chemists. The guide leads users through a series of questions to help them consider what is important for communication. The guide is flexible enough to accommodate the broad range of activities captured under the heading of "communicating chemistry."

FINDINGS AND RECOMMENDATIONS

As part of its task, the committee was asked to consider options for future research and to make recommendations to advance the understanding and effectiveness of informal chemistry communication. In considering the research that led to the five-element framework, the committee identified the following areas as research gaps:

- research on informal learning and science communication specific to the field of chemistry, including public perceptions and understanding of chemistry;
- research on digital media for chemistry communication; and
- research on how current policies guiding chemistry education and training, research work, and funding influence the extent and quality of chemistry communication activities, and how these policies might be changed to provide more support for communication activities.

The committee also noted opportunities for collaboration across organizations and institutions to support the implementation of the framework. In light of these findings, the committee makes the following recommendations:

Recommendation 1: Chemists should apply the *Framework for Effective Chemistry Communication* to guide the design, implementation, and evaluation of chemistry communication experiences. In using the framework, chemists are encouraged to collaborate with experts of empirically based approaches to science communication, informal learning, and chemistry education.

Recommendation 2: Chemistry professional and industrial societies should encourage the use of the recommended framework by their members. These organizations should also facilitate or create avenues for the aggregation, synthesis, translation, and dissemination of research on the evaluation of and effective practices for communicating chemistry.

Recommendation 3: The National Science Foundation and other sponsor organizations should support research that examines the specific relationship between science communication, informal learning, and chemistry education through programs such as the Advancing Informal STEM Learning program (NSF, 2014). Such support should focus on areas where research is most needed to enhance the effectiveness of chemistry communication, including

- public perceptions and understanding of chemistry;
- digital media for chemistry communication; and
- chemistry research and education policy, including professional development opportunities.

Recommendation 4: Chemists and experts in empirical approaches to science communication, informal learning, and chemistry education should collaborate to study chemistry communication in informal settings. Research collaborations should focus in particular on the priority areas listed in Recommendation 3.

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PART A

THE EVIDENCE BASE FOR ENHANCED COMMUNICATION

CHAPTER ONE

Introduction

The public's trust in research depends on the honesty, openness, and objectivity of researchers in communicating their results of research to those outside of the research community. This responsibility can take time away from research, but public communication is essential given the pervasive influence of research on the broader society.

—InterAcademy Council/IAP, *Responsible Conduct in the Global Research Enterprise,* 2010

The centrality of science to modern life bestows an obligation on the scientific community to develop different and closer links with the general population. That convergence will help evolve the compact between science and society so that it will better reflect society's current needs and values.

—Alan Leshner, 2003

Chemistry is the creative human endeavor to understand all matter. Chemistry and, hence, chemists[1] are essential for understanding the world and advancing society. Chemicals are involved in energy production, food safety, forensics, biomedical technology, ecosystem sustainability, and more and are therefore at the heart of many of society's conversations, such as those about the safety of food and medicines, the consequences of ocean acidification, ensuring access to clean water, and the mechanisms and effects of climate change.

Chemists seek to understand the interactions between molecules and how those interactions produce our macroscopic world. For many reasons—a sense of responsibility for bringing the voice of science to a conversation, a desire to share the joy of chemistry, a drive to encourage the next generation to pursue chemistry as a career, or others—many chemists endeavor to engage with members of the public. However, there is little guidance for chemists

[1] A chemist is defined as any professional who works in chemistry-related activities, including but not limited to research, analysis, manufacturing, engineering, education, and science policy.

on how to define communication goals, select a communication mechanism, or improve the effectiveness and reach of communication activities. An evidence-based framework for communicating chemistry is needed.

STUDY APPROACH

Given the value and importance of chemistry in addressing societal challenges and its potential to stimulate wonder and interest about our world, the National Science Foundation (NSF) asked the National Academies of Sciences, Engineering, and Medicine (the Academies) to develop an evidence-based framework to guide chemists' communication activities in informal settings. NSF asked the Academies to describe current efforts to communicate chemistry, to identify effective strategies, tools, and venues to engage members of the public in chemistry, to provide case studies of effective approaches, and to characterize a framework that can be used to evaluate the effectiveness of communication approaches. (See the Statement of Task in Box 1-1.) NSF also expressed interest in new tools and interfaces that might improve and expand chemistry communication.

To carry out the Statement of Task, the committee deliberated on two key questions: (1) Who are the primary report audiences? (2) What are the most effective mechanisms, given the study resources, to gather data?

The committee identified two primary audiences based on the Statement of Task:

- professionals working in basic and applied chemistry and the organizations that support their efforts to engage the public with chemistry, and
- institutions and professionals of informal science education who collaborate with chemists or their organizations to expand and enhance efforts to feature chemistry in their venues.

In regard to data gathering, the committee first commissioned a landscape study by the Education Development Center (EDC) and Grunwald Associates to provide an overview of informal communication activities related to chemistry. EDC researchers examined relevant material that was available online and in print media, held online discussions via LinkedIn, and interviewed stakeholders in the community to identify the types of events occurring, the venues, and the common goals of the chemists engaging in informal communication efforts. The committee used the results of the EDC study to tailor the report, in part, toward existing communication activities in the chemistry community. Second, the committee commissioned a white paper by Vera Michalchik of Stanford University, an expert in learning sciences, to provide a review of the literature on the evaluation of informal activities. The white paper formed the basis of this report's chapter on evaluation. Both the EDC study results and the

BOX 1-1
Statement of Task

The proposed activity will characterize current efforts to communicate chemistry in informal settings and draw on existing research in order to develop a framework for effective communication. This research will be made useful to individuals and groups involved in engaging the public with chemistry by linking it to scientifically based strategies on how best to address naïve mental models, common misconceptions, and lack of interest in chemistry. To achieve this goal, this activity will

- Identify where chemistry is being presented to the public (outside of formal school settings); how it is presented in these settings, the stated goals and objectives of informal chemistry communication, outreach, and education; and the perception of participants' needs on which these efforts in engaging the public with chemistry are based.
- Identify effective methods and techniques for engaging the public in chemistry by building on existing literature and studies on effective learning, communication, education, and outreach of science in informal and formal environments, including project and program evaluations, with additional input drawn from fields such as marketing, communications, and entertainment.
- Provide examples, in the form of case studies, of effective evidence-based chemistry communication, outreach, and informal education activities.
- Identify new and emerging communication and education tools and venues that show promise for providing opportunities to improve and expand chemistry communication, outreach, and education to various participant groups over the next 5 years (identify the current infrastructure of institutions and organizations that can support the chemistry community in its efforts).
- Develop recommendations for research and development on effective practices for informal chemistry communication, outreach, and education.
- Identify appropriate assessment and evaluation frameworks in the area of informal chemistry communication, outreach, and education.

An expert committee will synthesize this information into a conceptual framework that will identify a range of goals related to engaging the public with chemistry (e.g., increase awareness, generate interest, teach concepts, change behavior) and provide evidence-based strategies to accomplish each goal.

white paper are publicly available on the project webpage.[2] Third, the committee held four public meetings during which experts and practitioners in informal science learning, communication, chemistry education, and other subjects gave talks on how their work might inform a

[2] The landscape study and white paper can be accessed through the report webpage: www.nap.edu/catalog/21790.

framework for communicating chemistry in informal settings. Finally, the committee examined the current research literature in communication, informal learning, chemistry education, and other relevant social science fields.

WHAT IS CHEMISTRY COMMUNICATION?

In the physical and life science communities, the terms communication, engagement, education, and outreach are often used interchangeably. *Outreach*, in particular, is commonly used by the chemistry community to describe goals and activities related to interacting with nonexpert members of the public. However, in social science disciplines, science communication and related terms have specific disciplinary meanings and different sets of goals (see Chapter 4). For this report, the committee chose the terms *communication* and *participants* and interprets them as follows:

> *Communication: Any interaction outside of the classroom between members of the public of any age and members of the science community.*
>
> *Participants: Persons or groups that attend, use, or otherwise engage in a communication event.*

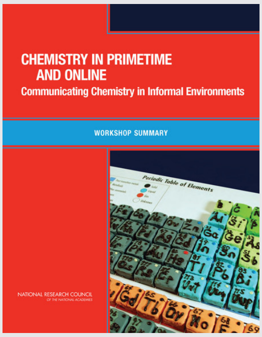
The committee chose *communication* because the term encompasses a wide array of interactions with members of the public, such as public lectures and informational videos, with an emphasis on two-way interactions, or *engagement*. Thus, we suggest that *communication* more aptly describes the range of chemistry communication events than do other terms, like *outreach. Communication* and *participants* were also chosen to link the social science language and evidence about effective communication with the events of chemistry communicators. Unless otherwise indicated, communication events discussed in this report take place in an *informal environment*—any setting outside of a formal classroom—such as community-based programs, after-school activities, museums, libraries, festivals, or home.

CHEMISTS ENGAGING IN COMMUNICATION

Chemists already participate in a wide range of communication activities, including giving public lectures; writing books, blogs, and other Web-based materials; participating in hands-on learning activities in museums; and using online engagement platforms to improve public access to and understanding of chemistry. A 2011 National Research Council (NRC) workshop *Chemistry in Primetime and Online: Communicating Chemistry in Informal Environments*[3] (Box 1-2) demonstrated that chemists communicate through video, television, radio, art, video games, and a variety of other digital media. Current modes of digital communica-

[3] See http://www.nap.edu/catalog/13106 [accessed February 2016] for more information.

BOX 1-2
Chemistry in Primetime and Online: Communicating Chemistry in Informal Environments: Workshop Summary



In 2010, the National Research Council's Chemical Sciences Roundtable hosted a workshop to examine how the public accesses scientific information from informal environments, and to discuss methods that chemists can use to improve and expand efforts to engage with nontechnical audiences. The workshop highlighted a variety of communication activities coordinated by members of the chemistry community, including developing museum exhibits, performing demonstrations, presenting chemistry on radio or in films, and using video games to teach concepts of chemistry. See http://dels.nas.edu/global/bcst/Communicating-Chemistry for further information.

tion on the Internet, such as video sharing (e.g., YouTube), social networking (e.g., Facebook), and microblogging (e.g., Twitter), present new opportunities for chemists to communicate with members of the public. At the workshop, the chemistry community's interest in engaging with the public was clear, but many workshop participants did not use a systematic approach to develop and implement their activities.

Chemists often work through professional chemical societies and other science organizations to interact with and inspire the public about chemistry. During the 2011 International Year of Chemistry (IYC 2011; Box 1-3), chemists around the world participated in discussions, science cafés, demonstrations, and more with students and members of the public. The International Union of Pure and Applied Chemistry (IUPAC) and the United Nations Educational, Scientific, and Cultural Organization coordinated the events. IUPAC and other professional chemistry organizations are considering the legacy of the IYC 2011 and how efforts to support the public's interest in chemistry can be continued.

In the United States, the American Chemical Society (ACS) is a leader in coordinating chemistry-related communication through local and national activities. The IYC 2011 prompted ACS members and the organization itself to develop new connections within and outside the chemistry community. Since the IYC 2011, the ACS has coordinated symposia and activities at national meetings to support a continued focus on communication activities.

Global activities during the IYC 2011 included collecting data about water quality from around the world onto one shared site. Various nations supported activities relevant to their communities. An archive of the activities hosted over the year and reported to IUPAC is at

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

BOX 1-3
The 2011 International Year of Chemistry

The International Year of Chemistry encouraged chemists and organizations around the world to engage in outreach with the public in both formal (classroom) and informal settings. Chemists developed interactive, entertaining, and education activities that focused on the theme "Chemistry—our life, our future."

http://iyc2011.iupac.org, and the final report is downloadable from the IUPAC website at http://www.iupac.org/project/2012-009-1-020.

Efforts within the chemistry community to promote communication with the public are mirrored by a focus on communication in the science community as a whole. From the conferences and training workshops of the American Association for the Advancement of Science, to the recent formation of the Science of Science Communication program at the University of Pennsylvania's Annenberg Public Policy Center, to the rise in the number and popularity of science festivals and cafés, communication with the public is a topic of conversation and interest in many segments of the scientific community. This push to communicate is also reflected in the number of recent activities, reports, and events that highlight the importance of scientists engaging in communication. Box 1-4 contains a list of some recent publications of the Academies in this regard.

As described in Chapter 2, there are a number of reasons that individual scientists, including chemists, choose to communicate with the public. One reason worth noting (for U.S. scientists) is the NSF Broader Impacts criterion, which requires that research proposals include "the potential of the proposed activity to benefit society and contribute to the achievement of . . . societal outcomes." A potential outcome listed as an example in the NSF grant-proposal guide is "increased public scientific literacy and public engagement with science and technology" (NSF, 2013), which is a powerful incentive for academic chemists and other scientists to include communication as a component of their professional work.

CHALLENGES OF CHEMISTRY COMMUNICATION

Chemists face three challenges to communicating: public perceptions of chemistry are unclear, the quantity and accessibility of chemistry-related content suitable for informal set-

BOX 1-4
List of Selected Academies Publications on Science Communication and Informal Science Learning

2015

Identifying and Supporting Productive STEM Programs in Out-of-School Settings

Integrating Discovery-Based Research into the Undergraduate Curriculum: Report of a Convocation

Food Literacy: How Do Communications and Marketing Impact Consumer Knowledge, Skills, and Behavior?: Workshop in Brief

Public Engagement on Genetically Modified Organisms: When Science and Citizens Connect: Workshop Summary

Trust and Confidence at the Interfaces of the Life Sciences and Society: Does the Public Trust Science?: A Workshop Summary

2014

STEM Learning Is Everywhere: Summary of a Convocation on Building Learning Systems

Characterizing and Communicating Uncertainty in the Assessment of Benefits and Risks of Pharmaceutical Products: Workshop Summary

Sustainable Infrastructures for Life Science Communication: Workshop Summary

The Science of Science Communication II: Summary of a Colloquium

tings are low, and there is no cohesive, science-based guidance for designing and evaluating chemistry communication activities.

During the nineteenth century, chemists generally enjoyed public support because of advances in medicine, color dyes, and other materials (Hartings and Fahy, 2011). However, public perceptions of chemistry eroded during the twentieth century. The use of chemical weapons during the world wars, the 1984 methyl isocyanate gas leak from an industrial complex in Bhopal, India, and the 2010 Deepwater Horizon oil rig explosion in the Gulf of Mexico are examples of large-scale incidents that may have contributed to public distrust of chemistry. Some scholars suggest that "chemophobia," described as both anxiety about chemistry as an academic subject and a fear of chemicals, has increased (Eddy, 2000; Hartings and Fahy, 2011). A recent survey by the Royal Society of Chemistry (RSC) indicates that chemists' concerns about public chemophobia are unfounded in the United Kingdom (RSC, 2015). A 2002 telephone survey conducted in the United States, however, suggests that the chemical industry is viewed least favorably in comparison with 10 other industries, including pharmaceutical, agricultural, and medical, but that members of the public have a positive view of chemistry as a profession (NSB, 2002). Comprehensive studies on public perceptions of chemistry and the prevalence of chemophobia have not yet been done in the United States. The lack of understanding of these public perceptions and attitudes toward chemistry makes it difficult to design participant-centered chemistry communication activities.

Most members of the public only interact with chemistry in school and might not think of it much or appreciate its relevance in society. One survey shows that public understanding and attentiveness is lower for chemistry than for some other scientific fields, even though the majority of respondents felt that chemicals make everyday life better (NSB, 2002). This lack of interest extends to the sharing of articles: A recent survey of social media sharing habits indicated that articles written by chemists were the least shared articles of any in the disciplines evaluated (Figure 1-1). Although chemistry is embedded in topics that receive greater visibility, the field itself is not often discussed. This pattern is reflected in the number of news items and social media mentions related to announcements of Nobel Prizes in chemistry compared with those in physics and in medicine or physiology.

Before entering school and after graduating, most people primarily encounter science in informal environments, such as museums, news media, Internet websites, and videos. Americans spend approximately 95 percent of their lives outside of classrooms; hence, informal learning activities can reach people over a much greater percentage of their lifetimes than can formal schooling (Falk and Dierking, 2010; NRC, 2009).

Increasing and improving public exposure to chemistry in informal settings can raise awareness and understanding of chemistry. Two examples that are popular are Sam Kean's 2011 best-selling book, *The Disappearing Spoon: And Other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements,* and Deborah Blum's blog *Elemental.*[4] However, even people who avidly seek out science in informal settings are less likely to interact with chemistry content than with the content of other science disciplines (NRC, 2011; Zare, 1996). Increasing the materials available and the opportunities to learn about chemistry in informal settings is insufficient in itself.

[4] See http://www.wired.com/category/elemental [accessed September 8, 2015] for more information.

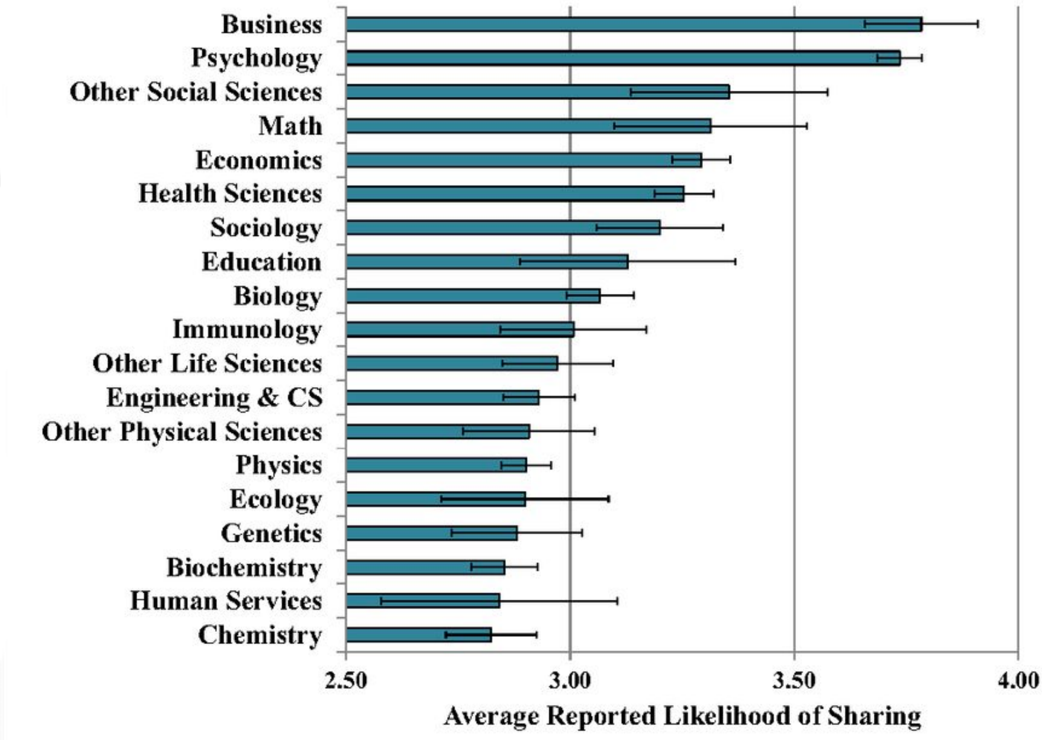


FIGURE 1-1 Average likelihood of being shared online by author's scientific field.
NOTE: CS = computer science.
SOURCE: Milkman and Berger, 2014.

TOWARD IMPROVING CHEMISTRY COMMUNICATION

An important but underused resource for improving approaches to science communication is research in the social sciences on chemical education, on informal science learning, on marketing, and on the science of science communication. There is a rich history of research on chemistry education in the classroom, but little guidance has been provided for chemists who wish to engage in communication with the public in informal environments. Professional organizations (such as the ACS) and the public information offices of research institutions have long facilitated media coverage of chemistry, removing the responsibility from chemists. However, museums, science centers, and related organizations have engaged in activities to support informal science learning for many decades, and the past decade has yielded important advances in formalizing relevant theory, research, and data collection efforts.

An example is the formation of the Center for Advancement of Informal Science Education (CAISE) in 2007 by NSF and the Association of Science-Technology Centers, to foster a community for sharing research on informal science learning. In 2009, CAISE published a report titled *Many Experts, Many Audiences: Public Engagement with Science and Informal Science Education* that reviewed practices that foster public awareness and participation. Also in 2009, the NRC publication *Learning Science in Informal Environments* reviewed the literature, identified six strands of learning, and provided a common framework for future research.

Principles of effective science communication have developed during the past 30 years (Brossard and Lewenstein, 2010). Events such as the 2013 and 2014 Sackler Colloquia on *The Science of Science Communication* and the 2013 meeting on the *Evolving Culture of Science Engagement* have expanded research in the discipline and translated that research into effective strategies for public engagement with science (Fischhoff, 2013; Kaiser et al., 2013; NRC, 2014; Scheufele, 2013). The January 2014 special issue of *Public Understanding of Science* provided a series of papers examining the past two decades of public engagement activities and research (Bauer, 2014).[5] Science communication is also the subject of long-running and ongoing work by many professional social science organizations, including the Risk Communication group of the Society for Risk Analysis, the Environmental Communication group of the International Communication Association, and the Science, Health, Environment and Risk group of the Association for Education in Journalism and Mass Communication. Advances in those fields of study are instructive for forming frameworks that aid the chemistry community in the design, implementation, and evaluation of public communication activities.

Each advance in informal science learning and science communication adds perspective, but none have yet provided a comprehensive conceptual approach for communicating chemistry. The value of social science research in addressing public communication problems is being examined for science as well as chemistry (Baram-Tsabari and Osborne, 2015), but the discussion is relatively new. These social science research areas provide insight for the present study, but their application to challenges specific to chemistry has not been considered before now.

One area of social science research that the committee considered was the work of citizen science. Given the variations in definition of that term in the community and the literature, the committee chose not to include it as a separate category in its review, although some related activities are included under the heading of informal science learning activities.

STRUCTURE OF THE REPORT

The report is organized into two sections. Part A includes six chapters in which the theoretical and evidentiary underpinnings of informal learning, science communication, and chemistry education are presented. Chapter 1 is an introduction. In Chapter 2 the value proposition for chemists and science organizations to communicate with members of the public is discussed. The personal and professional drivers that support a chemist's decision to develop

[5] *Public Understanding of Science* special issue: Public engagement in science. http://pus.sagepub.com/content/23/1.toc [accessed June 12, 2015].

or support communication activities are also described in Chapter 2. Chapter 3 synthesizes the results of a landscape study on goals and activities of chemistry communication in the United States and presents case studies to illustrate methods for characterizing such activities. Chapter 4 describes goals, challenges, and key principles for informal learning, science communication, and chemistry education. Chapter 5 focuses on evaluation, including an overview of current research related to evaluation of informal science learning. Chapter 6 lays out the committee's framework for the design of effective communication activities, based on the evidence presented in the previous chapter. Chapter 6 also describes key areas for future research to support the development and implementation of chemistry communication activities and lists the committee's recommendations.

Part B, *Communicating Chemistry: A Framework for Sharing Science,* is a user-friendly guide to the framework for designing chemistry communication activities. The goal of this guide is to help chemists improve the design and evaluation of their communication activities in informal environments.

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EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

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CHAPTER
TWO

Why Chemists Engage in Communication

What motivates chemists to communicate with members of the public? A 2012 analysis of surveys of American Association for the Advancement of Science (AAAS) and Royal Society of Chemistry members revealed that "[i]n terms of perceptions and motivations, a deficit model view that a lack of public knowledge [of science] is harmful, a personal commitment to the public good, and feelings of personal efficacy and professional obligation are among the strongest predictors of seeing outreach as important and participating in engagement activities" (Besley et al., 2012). Matlin, Mehta, and Hopf argued in a recent editorial in *Science* that "[c]hemists must continue to improve their conversations with the public" to support a goal of continuing support of chemistry as "the great enabler" (Matlin et al., 2015). As part of the landscape study commissioned by the committee, Grunwald Associates interviewed chemists who were involved in various education and communication activities. These individuals noted many personal and professional motivations and goals for engaging in communication; one chemist stated, "Personally I've made it my mission to change attitudes towards chemistry." The chemists also often noted that they developed the communication activities to fulfill funding requirements, such as the National Science Foundation's (NSF's) Broader Impacts criterion.

CHEMISTS' GOALS FOR COMMUNICATING SCIENCE

After reviewing the input from the landscape study (summarized in Chapter 3), the committee identified four leading goals[1] of chemists who engage in public communication:

1. increase public appreciation of and excitement for chemistry as a source of knowledge about the world,
2. develop scientifically informed consumers (i.e., consumers will be able to use chemistry information to make decisions or solve problems),

[1] Goals are statements of what the communication activity intends to accomplish and are not measurable. Intended outcomes, the development of which is discussed in Chapter 5, are specific to a given activity and should be measurable.

3. empower informed citizen participation in democratic processes, and
4. encourage workforce development in the chemical sciences.

The following sections briefly examine each of these goals. Though these goals are specific to the chemists interviewed in the landscape study, they accord with some of the motivations for engagement found in surveys of scientists in general (Besley, 2013; Besley et al., 2012). These four goals, however, are only a subset of possible goals for science communication (see Chapter 4).

Goal 1: Increase Public Appreciation of and Excitement for Chemistry as a Source of Knowledge About the World

"Everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world." (NRC, 1996, p. 1)

One commonly cited reason for engaging in chemistry communication with the public is that it serves a personal and intellectual need, "broadly framed as knowledge for the sake of knowing more about the world and how it works, addressing human curiosity in ways that go beyond instrumental needs for practical knowledge" (NSB, 2012, pp. 7-27). Many of the interviewed chemists feel that chemistry is a fascinating and powerful tool for understanding and affecting the world. They want to share their appreciation for the field as a way of knowing more about the world and creating new areas of knowledge for others. This is highlighted in two quotes from members of the American Chemical Society (ACS) who reflected on the question "Why are you proud to be a chemist?"[2]

> The most rewarding aspect of chemistry is the possibility it gives for us to exert our creativity. The synthesis of a new compound or the improvement in an existing technology requires a lot of creativity. I am proud to be a chemist because I know that chemistry can help humankind solve many of our problems, such as global warming, diseases, energy, and many others.
>
> —Claudio J. A. Mota, ACS Member

> I don't know of many disciplines that open up the world the way chemistry does because it touches everything. I would be hard pressed to think of something where chemistry isn't playing a role in the advances that we benefit from today—from breakthroughs in medicine, to nutrition, to more sustainable energy sources, to personal care products, to biodegradable packaging, and so on.
>
> —Mary Carmen Gasco-Buisson, ACS Member

[2] See https://www.acs.org/content/acs/en/volunteer/chemambassadors/aboutchemistry/why-im-proud-to-be-a-chemist.html [accessed September 8, 2015] for additional information.

Many of the interviewed chemists feel a desire to share their excitement and understanding with others and choose informal settings to do so. However, there is only anecdotal evidence that communicating chemistry in informal settings can generate excitement. But, there is evidence that experience with chemistry before formal study can improve confidence and consequently understanding of chemical concepts (Fadigan and Hammrich, 2004; NRC, 2007). Thus, chemists sharing their excitement can increase the understanding of chemistry.

Goal 2: Develop Scientifically Informed Consumers

"Everyone needs to use scientific information to make choices that arise every day." (NRC, 1996, p. 1)

A second purpose of communicating chemistry is the development of scientifically informed consumers. Scientific "knowledge facilitates decision-making in everyday life, particularly when [science and technology] intersects with citizens' work, home, and leisure activities" (NSB, 2012, pp. 7-27). Chemistry, as is commonly stated, is "the central science," and chemists are keenly aware of its relevance in day-to-day decision making with regard to products and services. To nonexperts, however, chemistry is complex and abstract; it is difficult to understand because molecules and their interactions cannot be directly observed. Its relevance to daily life is unclear. Some individuals identify with one of two extremes, either "all chemicals are harmful" or "everything is made of chemicals so there is nothing to worry about" (e.g., Glynn et al., 2007; Nieswandt, 2007). One reason for these disconnects is that it requires a conceptual leap to understand how such small things as atoms and molecules can cause large changes in properties or behavior (Brunsell, 2011; Hartings and Fahy, 2011; NRC, 2011). As one LinkedIn commenter stated in the landscape study, "the notion that all chemistry happens in a lab somewhere, rather than on your dinner plate, or in the sky, or in your car or your body every day" is "a tough nut to crack." However, individuals do not necessarily require an understanding of molecular-level processes to appreciate how chemistry can support decision making. As will be discussed, engaging in communication with the public in informal environments provides opportunities to showcase real-world examples of chemistry and to increase public awareness of chemistry's roles in various aspects of society.

Goal 3: Empower Informed Citizen Participation in Democratic Processes

"Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology." (NRC, 1996, p. 1)

"Public knowledge about [science and technology] facilitates civic engagement with science, particularly when technologies raise emerging issues that intersect science and society." (NSB, 2012, pp. 7-27)

A third purpose for communicating chemistry to different publics is to support a scientifically engaged citizenry. The ability "to assess how a product or system will affect individuals, society, and the environment . . . is particularly important today because the human use of technology has become so widespread that it can result in positive or negative consequences, and it is so complex that it can be difficult to predict" (ITEA, 2007, p. 133). This goal is of particular interest to chemists because the impacts of chemistry that gain the widest public attention are the negative effects of oil spills, lead poisoning, nuclear fallout, and other health and environmental disasters (Gregory and Miller, 1998; Hartings and Fahy, 2011), and in a 2000 survey by the ACS, the chemical industry was ranked the least favorable of 10 science-related industries (NSB, 2002). Engagement by chemists with the public can create the trust needed to navigate difficult and important topics. As noted by Alan Leshner, the former Chief Executive Officer of AAAS, "We need to engage the public in a more open and honest bidirectional dialogue about [chemistry] and [its] products, including not only their benefits but also their limits, perils, and pitfalls. We need to respect the public's perspective and concerns even when we do not fully share them, and we need to develop a partnership that can respond to them" (Leshner, 2003). In other words, sharing chemistry can empower publics to make informed decisions.

Goal 4: Workforce Development

"More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the processes of science contributes in an essential way to these skills." (NRC, 1996, p. 1)

Workforce development is a strong driver of formal education in any field, and chemistry is no exception. Unfortunately, formal education in chemistry, though certainly able to attract and engage some students, also leads to anxiety and avoidance of the subject in many high school and college students (Nieswandt, 2007). As discussed in a prior section, experience with chemistry before formal study can promote confidence, which may reduce the effects of negative associations with chemistry. Informal experiences also have the potential to provide real-world context, to increase relevance, and to engage children at a young age before they encounter chemistry in school. As noted in the 2009 National Research Council (NRC) report *Learning Science in Informal Environments*, "Anderson et al. (2002) found that, for children, experiences that were embedded in familiar sociocultural contexts of the child's world, such as play, story, and familiar objects, acted as powerful mediators and supported children's recollections and reflections about their activities" (NRC, 2009, p. 156). When science (chemistry) satisfies a child's proclivity to play, the science becomes more relevant; such experiences cast the subject in a positive light and reduce future anxiety.

When chemists engage in communication, they can present themselves as role models for people considering careers in the sciences; they can support a sense of belonging, which in turn supports the development of an identity as a scientist. For students who belong to a group underrepresented in science, role models can be especially important in establishing an identity within a particular field (Baker, 1992; Fort et al., 1993).

Popular role models, both fictional and nonfictional, also attract young people to the sciences. Television shows and movies present role models in medicine, law enforcement, military fields, and more recently forensic science. The so-called CSI effect is credited with increasing enrollment in forensic science programs across the country (Jackson, 2009; Smallwood, 2002).

Given the impact that the television show *CSI: Crime Scene Investigation* had on forensic science, one might ask, "Who are the popular role models for chemistry?" In 2013, *Breaking Bad*, a television series that won 10 primetime Emmy Awards and a Guinness World Records citing for the highest-rated TV series of all time, featured a high school chemistry teacher who began producing and selling methamphetamine to secure his family's financial future in anticipation of his death from inoperable lung cancer.[3] Although this character's care for his family is admirable, his use of chemistry for criminal purposes makes him a poor role model. Other shows, such as the recent documentary *Percy Julian: Forgotten Genius*, provide real-world examples of excellence in chemistry. Unfortunately, there are few popular chemist role models on a national or international scale. Therefore, chemists everywhere can help address this need by serving as role models on a local level.

THE ROLES OF CHEMISTS IN COMMUNICATING IN INFORMAL SETTINGS

As discussed below, chemists themselves contribute in at least three ways to learning chemistry in informal environments: as sources of content, as sources of credibility, and as bridge builders with other groups.

Chemists as Sources of Content

Chemists play an important role in chemistry content for informal environments. Providing chemistry content can be challenging. In science museums, for example, unsupervised, hands-on activities demonstrating physics principles are easier to provide cleanly and safely than activities for chemistry: balls, pendulums, springs, and mirrors that people can interact with (unstaffed) to learn about physics are easier to set up and safer than are the acids, bases, flames, and explosions of chemistry. Engaging, concrete, active, and interactive demonstrations of chemistry require live presenters. Those presenters need to know chemistry, which can

[3] For a deeper discussion about the representations of chemistry and chemists in popular culture, see "The Chemist as Anti-hero: Walter White and Sherlock Holmes as Case Studies" (Fahy, 2013) and "Making the Science of TV Crystal Meth Clear" (Nelson and Lettkeman, 2013).

be accomplished by having presenters who are chemists themselves or who were trained by chemists.

The need for chemists as presenters is greater when the goal is public understanding of current research (Field and Powell, 2001). Even among informal science educators who know chemistry, few are probably up to date with current research. Chemists can thus support communication in informal environments by providing content on both chemistry fundamentals and current chemistry research.

Chemists as Sources of Credibility

In general, Americans rank scientists as more credible sources of scientific information than most others who might provide such information, such as the news media and regulatory agencies (see Figures 2-1, 2-2, and 2-3). Data show that scientists rank above medical

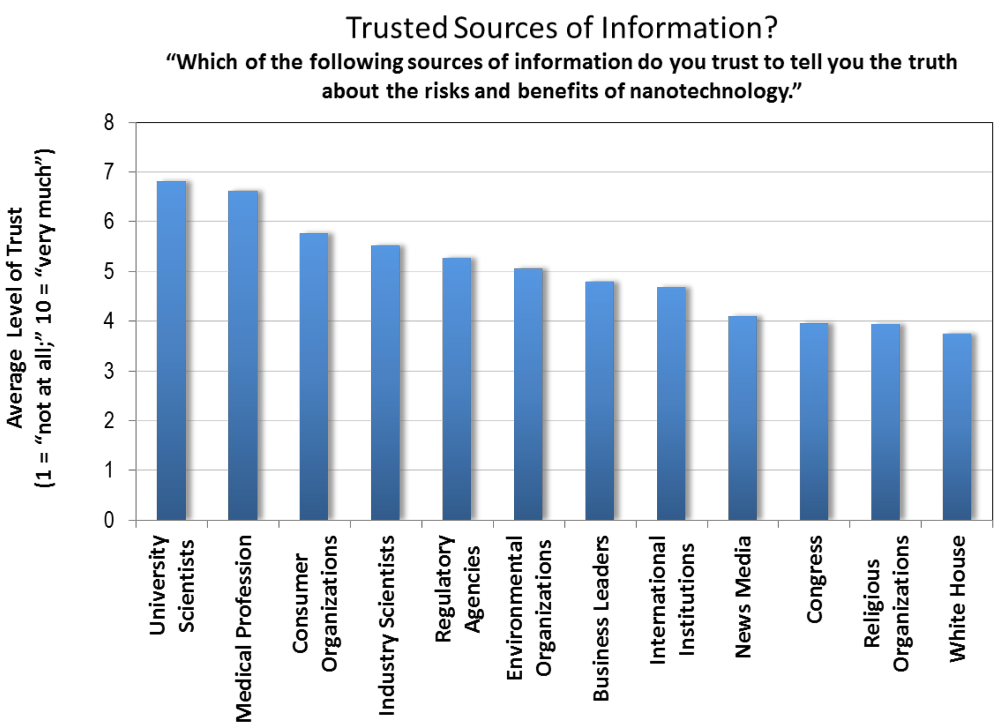

FIGURE 2-1 Responses to a survey on trusted sources of information about nanotechnology.
SOURCE: Based on data from Scheufele et al., 2009.

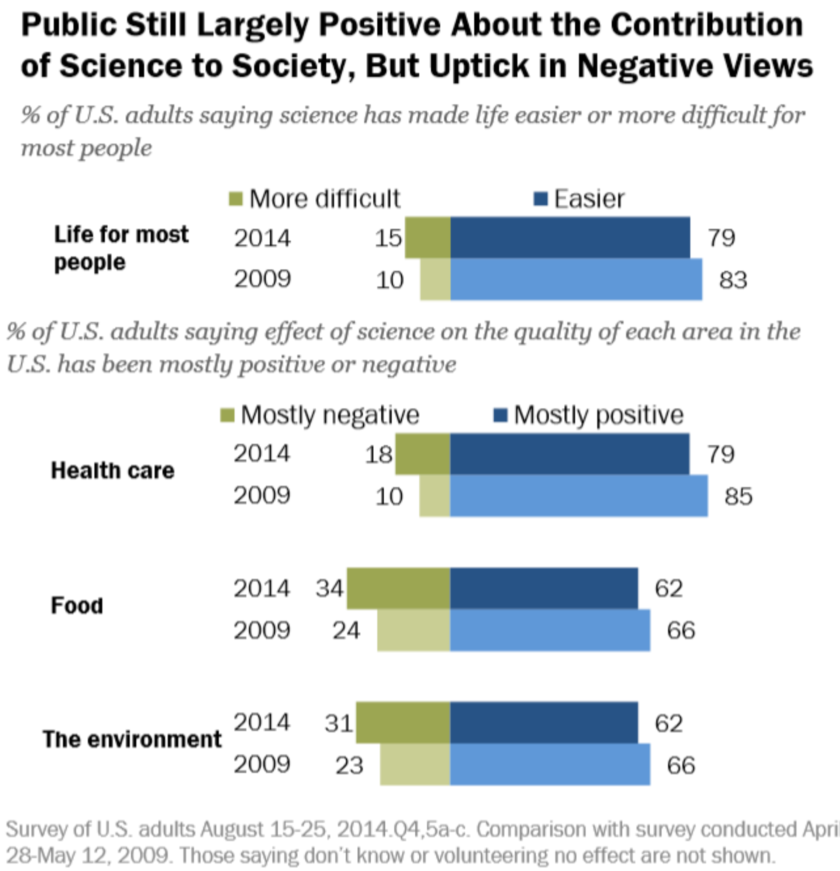

FIGURE 2-2 Public perceptions of the contribution of scientists to different areas from 2009 and 2014.
SOURCE: Pew Research Center, 2015.

doctors, industrial scientists, consumer organizations, and regulatory agencies, and far above religious organizations, the news media, the White House, and Congress, as a source trusted to tell the truth about nanotechnology (Figure 2-1). Data from the Pew Research Center indicate that scientists are generally considered to have a positive influence on society (Figure 2-2). The NSF's biennial *Science and Engineering Indicators* series shows that the public thinks scientists who are specialists in a scientific field understand both the science *and* the public issues related to that field better than elected officials, business leaders, or religious leaders. The public also has high confidence in the leadership of the science community, much higher than for government, industry, or the media (Figure 2-3).

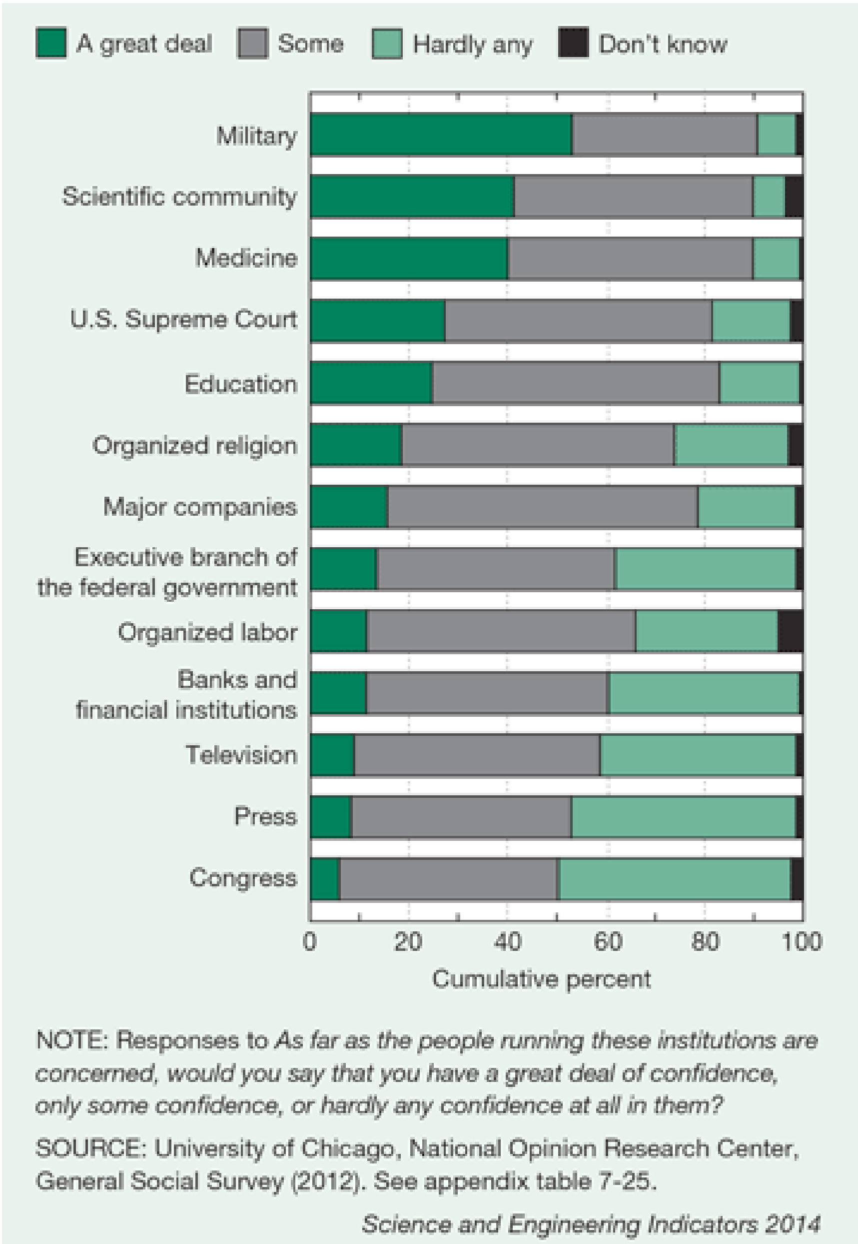

FIGURE 2-3 Public confidence in institutional leaders. Note that scientists are often perceived positively by the survey respondents.
SOURCE: NSB, 2014.

Chemists as Bridge Builders with Other Groups

Because chemists interact with scientists and engineers across a wide range of disciplines and sectors—from university research to industry to medicine to environmental engineering, among others—they have the opportunity, perhaps even a responsibility, to serve as bridge builders between those groups and from those groups to a range of publics. Pollster and analyst Daniel Yankelovich argued in 2003 that "top flight working scientists . . . can provide a depth of expertise that is sorely lacking in the generalists' discussions of scientific issues [and] they can also help their scientific colleagues understand the importance of nonscientific perspectives to their own work and the future of their field."

Occasions for the bridge builder role are increasing as science communication and public engagement activities increase. In particular, activities that focus on "dialogue" or have a "participatory democracy" approach are designed to connect scientists and publics. The bridges allow a two-way exchange of information and ideas, which is beneficial to both parties. As noted in the Center for Advancement of Informal Science Education (CAISE) report *Many Experts, Many Audiences* (McCallie et al., 2009) in the participation model, publics[4] and scientists both benefit from listening to and learning from one another—they engage in mutual learning. The CAISE report's model assumes that both members of the public and scientists have expertise, valuable perspectives, and knowledge to contribute to the development of science and to its application in society (Burns et al., 2003; Kerr et al., 2007; Leshner, 2003). The mutual respect inherent in the participation model is a key element for building trust among different groups; trust is key to building bridges and is necessary for the "partnership" that Leshner talked about between science and the public.

WHAT CHEMISTS GAIN FROM THEIR COMMUNICATION ACTIVITIES

Chemists benefit from participating in informal science learning and communication activities. They learn about social science disciplines that can improve their communication practices and about participants who attend the activities. Enhanced learning in these areas leads to other benefits, such as professional development, discussed below. There are also tangible benefits such as strengthening research grant applications.

Enhanced Learning About Informal Science Education and Science Communication

Informal science education and science communication are social science disciplines that may be unfamiliar to many chemists. However, chemists who participate in such activi-

[4] The term "publics" refers to the multiple communities that exist within the general public. These communities can be described by role (students, policy makers, etc.), age group, interest area, goal for participation, or some other factor that highlights a meaningful shared perspective or approach within a given context.

ties have the opportunity to learn about these disciplines' evidence-based principles and their approaches to communication (see Chapter 4).

Informal science education focuses on learner-motivated activities outside of school settings that are based on the learner's interests and can take place throughout life (McCallie et al., 2009; NRC, 2009). Despite the word "education," informal science education is more than the one-way transmission of knowledge from a scientist to a member of the public in an informal setting. Informal science education scholars are increasingly exploring *engagement* models (two-way, mutual learning experiences) between scientists and the public (Baram-Tsabari and Osborne, 2015; McCallie et al., 2009). Organizations and publications concerned with informal science education have proliferated over the past 50 years (NRC, 2009). Education research organizations, which usually focus on schools, have added special-interest groups devoted to informal learning and informal science. Numerous peer-reviewed journals have added special editions (or sections) on informal science learning, and new journals have arisen. In addition, with the rise of the Internet, research on and evaluations of informal science learning environments that used to be hidden in the gray literature have become more available through websites (such as www.informalscience.org); NSF has published a framework for assessing the impact of these environments (Friedman, 2008).

The focus of science communication is primarily engagement; learning is only one of many possible goals (see Chapter 4). Building trust, developing an awareness or appreciation of science in everyday life, acquiring information through media stories on Internet sites, and developing identity (all without an expectation of knowledge gain) are other possible goals. Science communication, previously called public understanding of science, formed as a formal discipline in the 1980s (Brossard and Lewenstein, 2010). Researchers in this area endeavor to act as bridges between the communication sciences and the physical and life sciences. Science communication research is expected to continue to expand rapidly in coming years.

Recent projects have demonstrated what physical and life scientists (including chemists) can learn from participating in informal science education activities. One such activity is the Nanoscale Informal Science Education Network (NISE Net), "a national community of researchers and informal science educators dedicated to fostering public awareness, engagement, and understanding of nanoscale science, engineering, and technology" (NISE Net, 2014) funded by NSF and led by 14 museums and universities across the United States. University-affiliated individuals who participate in NISE Net noted multiple benefits of participation. They value providing nanoscience learning activities to interested individuals, but they also recognize that participating provides them with valuable professional development; for some, this was the greatest benefit of participation. The professional benefits identified include an expansion of career focus, an improved ability to communicate about science research, and increased understanding of the pedagogical concepts drawn from the informal science community (Ewing, 2009; Goss and Kollmann, 2009; Kollmann, 2009; St. John et al., 2009).

The idea that learning techniques of informal science education is valuable for the university-affiliated individuals who participate in these activities appears repeatedly in evaluations of the activities. For example, the *Portal to the Public* project, which pairs university-affiliated individuals with science museums, found similar results: The scientists indicated that they both enjoyed and valued the basic communication training they received and learning new techniques for engaging with the public (Schatz and Russell, 2008). Similarly, an evaluation of the *Current Science and Technology* project at the Museum of Science in Boston revealed that

> even though participating scientists did not receive professional development [training] as a part of their involvement, they thought that this could be a valuable aspect of participation if it helped them think about how to best present their research to the public (Storksdieck et al., 2006). These findings all highlight the importance of providing professional development to university-affiliated individuals not only because it may improve their ability to present science content to the public, but also because university-affiliated individuals value the chance to learn about how to best provide informal education learning experiences. (Reich et al., 2011, pp. 54-55)

Collaborative science communication activities need not be on a large scale for benefits to accrue. A 2014 project examined the impact of communication activities run by the chemistry department at Rhodes University in South Africa. The researchers determined that an activity in which undergraduate students reached out to local teachers to provide them with content-related support benefited both the teachers (who reported tangible improvements in their approaches to working with students) and the undergraduate students (who expressed a change in their perception of themselves as science communicators; Sewry at al., 2014).

Informal science education organizations have developed knowledge about and skills for engaging the public in learning about science, and scientists appreciate the value of that knowledge and those skills:

> We live in a short-attention-span world, and although science is engaging by itself, scientists may not be the best candidates to come up with attention-grabbing ideas. Science museums are highly skilled at capturing the attention of young people. They do it all the time and do it well.
>
> —Ainissa Ramirez, Yale University (Alpert, 2013, p. 16)

The science community, particularly professional societies, has taken note of the benefits of communication training. For example, the ACS's Office of Public Affairs Expert Training Initiative teaches chemists how to participate in effective interviews for print and electronic media and offers support in writing editorials and making presentations to local, state, and national governments. Media training includes how to effectively give interviews. Chemists learn how body language impacts their message. They learn to determine how prepared (or unprepared) their interviewer is on the topic and how best to give an even-handed and accurate response to questions that are emotionally charged. Practice interviews, which are critiqued by media experts, help chemists understand how they are perceived by the public. NSF holds training sessions entitled "Becoming the Messenger" to achieve a similar goal; this training involves both the message and the delivery. AAAS, through its Center for Public Engagement with Science and Technology, offers Communicating Science Workshops. COMPASS, a boundary organization, provides training on public engagement and building networks between scientists and publics, such as policy makers. Training sessions with experts in science communication of science, as well as support from professional societies' media offices during a media "internship," are the support that chemists need to learn these new skills. As a result of this training, chemists are sharing their chemistry stories in ways that better match the questions raised by the public and engaging in a more personable and responsive manner.

Enhanced Learning About Participants

Key elements of public engagement are mutual learning and respect. Thus, these kinds of communication activities provide opportunities for chemists to listen to and learn about public perspectives on issues of mutual concern and to learn what the public (or a segment of the public) thinks about chemistry. The benefits to chemists of such dialogue were noted in interviews conducted by Inverness Research Associates in 2009 with scientists engaged in NISE Net public communication activities. The benefits included learning how to better communicate their own scientific interests to the public, fulfilling the Broader Impacts requirements of their NSF grants, and "learning from the public—getting a chance to hear their questions, issues, and concerns regarding nanoscience." A sample of scientists' comments includes the following (St. John et al., 2009):

- "Every time I've seen a scientist engaged with the public, they get a better understanding of their own research and its contact with society, and how their research actually impacts people and the environment." (p. 14)
- A benefit of this work is "just understanding what the concerns are of the general public, what they know, and what they don't know." (p. 10)
- "Engaging with the public is very motivating for graduate students and post-docs, and it helps them stay focused on why they are doing their research and how it benefits society." (p. 10)

At the first conference of the Society for the Study of Nanoscience and Emerging Technologies, Troy Benn and Carlos Perez, graduate students from Arizona State University (ASU), presented demonstrations they had created to engage and encourage kids and adults to consider the societal or environmental implications of a nanoscience project. ASU faculty members Jamey Wetmore and Ira Bennet encourage students to create such demonstrations. They have found that the questions raised by the public during engagement activities lead the students to consider their work in new ways and extend the students' awareness of the potential societal implications of nanoscience.

Strengthening Research Grant Applications

Participation in communication activities aids chemists applying for grants from NSF and other federal funding agencies. Many of these agencies now require or encourage development of or participation in communication activities that convey the societal relevance of research. Communicating chemistry in informal environments meets several of these requirements. "Outreach can provide connections with informal science education colleagues and open up avenues for collaboration that will address Broader Impacts requirements for proposals to the National Science Foundation and other agencies" (Crone, 2006, p. 2).

POTENTIAL BARRIERS TO ENGAGING IN COMMUNICATION

The benefits to chemists engaging in public communication (described previously) are clear, but there are challenges to achieving them. One critical element is the culture within the field. Chemists "do not actively work on communicating their research in ways that are approachable to non-specialists" (Hartings and Fahy, 2011), and, though opportunities to engage with the public have existed for years, such engagement has not been strongly encouraged until recently. A survey on scientists' motivations for engaging with the public revealed that chemists were the least likely to participate in activities designed to communicate with the public (Besley et al., 2012). However, initiatives such as NSF's Broader Impacts criterion and the push for outreach during the International Year of Chemistry 2011 (IYC 2011) have resulted in increased consideration of effective practices.

Velden and Lagoze (2009) posited that chemistry lags behind other sciences in the adoption of new communication and collaboration technologies (such as open access, preprint services, and science blogs) and identified contributing factors. These included chemistry's focus on creation, with limited emphasis on the development of theory; its large number of small research areas; its dependence on lab-based, rather than digital or computer-based, research; its diversity of research cultures; its proprietary nature, with industry incentives for secrecy; and the industry-academy imbalance, in which industry is more a consumer of than a contributor to research. Some of the factors that challenge communication within the field mirror the challenges of communicating chemistry to the public—such as chemistry's complexity, which leads to a perceived lack of disciplinary unity, and the fact that it is "messy."

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

Chemistry's Lack of Disciplinary Unity

Chemistry's central role in science has led to the topic being incorporated in a wide range of science research; some have characterized this wide incorporation as a lack of disciplinary unity. Chemistry includes a range of unifying ideas such as the atomic-molecular basis of matter, the concepts of equilibrium and reactions, or that quantum mechanics explains chemical bonding. And, the field of chemistry has dramatically progressed: from developing a fundamental understanding of the nature of matter, to (emerging from the industrial revolution) applying chemistry in industry, to developing tools that support the field. However, there is no sweeping explanatory theory like evolution in the biological sciences that creates a unifying narrative for chemistry or what it means to be a chemist (Hartings and Fahy, 2011; NRC, 2011).

Adding to the confusion is the tremendous overlap of chemistry with other fields of science. Many scientists doing chemistry do not think of themselves as chemists (NRC, 2011). For example, a 2009 editorial in *Nature Chemistry* addressed that year's Nobel Prize in chemistry, awarded to scientists studying the structure and function of the ribosome, which many consider a topic of biology. The editorial wrestled with the ideas behind disciplinary distinctions, a recurring theme in discussing chemistry in the context of the communication of science (Questioning "chemistry," 2009). The journal resumed the discussion in 2011, discussing goals and aspirations at the start of IYC 2011 (Chemistry's year, 2011). That editorial cautioned of the danger that chemistry becomes so diffuse across different areas that it loses its identity. One example of the impact of this diffusion is portrayals of chemistry in the media, where it is frequently organized by its application (NRC, 2011). Although this organization makes sense as a response to the abstract nature of chemistry (cited above), it raises the issue of how chemists, with their collective focus so diffuse, will know that chemistry matters.

Chemistry Is Messy

The fact that chemistry experiments and demonstrations are often messy and potentially dangerous (or thought to be so) is cited by many informal science educators, especially those working in museums and other informal settings, as a challenge in chemistry communication (Keneally, 2014). The challenge of including chemistry in science museums is not new. In a 1990 Association of Science-Technology Centers survey of science museums and science centers, 28 percent of science museums reported no chemistry activities and less than 30 percent reported chemistry exhibits (Zare, 1996). More recently, Silberman noted that chemistry continues to be one of the least represented disciplines in science museums (Silberman et al., 2004).

ENGAGING IN COMMUNICATION

The benefits to the public and to the field of chemistry merit continued communication and engagement in spite of the challenges. We can draw on the expertise of the fields of informal science learning, science communication, and chemistry education to provide guidance to those who are actively developing and implementing communication activities. Chapter 4 provides an overview of the relevant research in these fields that supports the framework described in Chapter 6.

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CHAPTER THREE

The Current State of Chemistry Communication

The previous chapter provided an overview of the role that chemists can personally and professionally play in communication. In developing the framework, the committee needed to increase its knowledge of the types of activities described as "communicating chemistry." This chapter offers a characterization of current activities.

The landscape study commissioned by the committee and performed by Grunwald Associates and the Education Development Center included

- a literature review;
- interviews with National Science Foundation (NSF) program officers and other experts in chemistry communication;
- descriptions of NSF projects related to communicating chemistry (not including projects where communication activities were solely part of the Broader Impacts requirement);
- web searches for chemistry in science media; and
- a semistructured, multiweek discussion with the 1,800-member NSF Media and Informal Science Learning group on the LinkedIn social network site.[1]

Although necessarily limited in scope and focus, the landscape study provides the best available snapshot of current chemistry communication activities in the United States. This chapter draws heavily on the landscape study and contains many passages from the report.

The landscape study uncovered a wide range of communication events, conducted in a variety of settings for different participants. These events include science museums designing exhibits for all ages; university-based chemists engaging in lectures and community events; science journalism appearing in popular media (print, radio, or television); entertainment media featuring chemistry (e.g., *Breaking Bad* and *CSI*); blogs and online media addressing particular issues and interests; informal science, technology, engineering, and mathematics

[1] For more detail, see https://www.linkedin.com/grp/home?gid=1851525 [accessed June 12, 2015].

programs engaging young people in investigations; and nonprofits offering adult classes about chemistry in everyday lives. The types of event format range from traditional lectures and demonstrations to newer formats, such as flash mobs and science pubs. There also has been considerable growth of chemistry communication on the Internet through videos, science blogs, podcasts, and social media.

Although it is impossible to discover and describe all chemistry communication activities, it is valuable to be aware of their diversity. Given the goal of promoting a more systematic design of these activities, it is useful to categorize them. The landscape study therefore identified key categories that describe this diversity. Understanding the general dimensions of chemistry communication activities—and the ways in which they vary—was key to developing the framework presented in this report.

PREVALENCE OF CHEMISTRY COMMUNICATION ACTIVITIES

A common refrain among chemists and other experts is that "chemistry is everywhere" (Grunwald Associates and Education Development Center, 2013). However, when it comes to communication activities, chemistry is less common than either biology or physics[2]—though chemistry activities are arguably more diverse. For example, chemistry plays a role in topics like antibiotic resistance, nanomaterials, and gems and crystals, but discussions of these topics may not mention molecular interactions, reactivity, crystal structures, or other chemistry concepts.

Chemistry was just one of many topics in science, technology, engineering, and mathematics that organizations in the landscape study addressed in their educational programming. In many cases, the inclusion of chemistry depended on the training and background of an organization's leadership staff: if someone on staff had expertise in chemistry, chemistry was much more likely to be included.

Professional organizations such as the American Chemical Society focus explicitly on chemistry, and many long-standing institutions of science communication include chemistry in their programming. For example, the "Marvelous Molecules" exhibit at the New York Hall of Science showed visitors the chemistry of living things. PBS's science program *Nova* produced a 2-hour special called "Hunting the Elements," originally aired in April 2012, which explored the periodic table. Other organizations facilitate activities, including science cafés and lecture series, on a chemistry topic of interest, such as the chemistry of beer or facts about pesticides.

[2] For example, a search of the informalscience.org database using Boolean terms physio*, biolo*, and chemi* returned 442 physics-related projects, 314 biology-related projects, and 117 chemistry-related projects, as of January 26, 2016.

CHEMISTRY CONTENT

Although the landscape study found that some chemistry communication activities are designated as such, chemistry is often integrated with and presented as part of another science field. An activity may include chemistry concepts but is not described to participants as chemistry. Based on original research and reviews of the literature, the landscape study presented four categories that describe how chemistry content is most frequently treated in communication activities. This set of categories is not exhaustive.

- **Chemistry:** The term "chemistry" describes communication efforts that *explicitly* involve the core principles and applications of major branches of chemistry (e.g., organic, inorganic, analytical, physical, and atmospheric) or of chemical engineering. The communication efforts in the landscape study mostly related to biochemistry and materials chemistry, though it is likely that there are communication activities in the United States about all areas of chemistry.
- **Everyday chemistry:** Everyday chemistry activities investigate the role of chemistry in the things we do, see, or use every day. Topics addressed in everyday chemistry activities include food and cooking, health and medicine, gardening and agriculture, and products such as cosmetics, fabrics, plastics, and cleaners.
- **Environmental science:** Many chemistry communication efforts involve issues of the environment. Examples in the landscape study included activities responding to current events, such as oil spills, and explaining concepts such as the carbon cycle. Other activities address climate change and global warming, natural and alternative resources, and energy.
- **Chemistry in other disciplines:** Some communication efforts include chemistry within another science discipline. These activities refer to the role that chemistry has in areas like astrophysics, biotechnology, medicine, nanoscience, and forensic science.

DURATION AND VENUE

Chemistry communication activities vary widely in length and occur in a wide variety of spaces (Falk and Dierking, 2010; NRC, 2009, 2011).

Duration

In this report the committee defines *events* as one-time activities and ongoing programs; it defines *activities* as one-time communication or learning experiences that bring together one or more experts and a group of participants. The traditional public lecture, in which one or more experts make a presentation to the community, has long been a form of chemistry communication. Articles in newspapers or magazines are also considered activities. Other

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

common examples include demonstrations in malls or other settings, formal or informal talks to community groups, science fairs (at which chemists volunteer or mentor), and activities for student or youth groups. More recently, the public lecture has been transformed into more-informal opportunities for chemists to share their knowledge and respond to participant questions; the committee's research uncovered a variety of such activities, including pub nights and food demonstrations. Activities also include science festivals, which are growing in number around the country, and performances in which chemistry concepts are communicated through theater, music, or art.

Some chemists are involved in long-running programs, but usually chemists participate in only one (or more) session of a program. Programs fall into two categories: those that serve youth and families, and those that serve adults. After-school programs expand science learning for students. Adult programs, such as evening classes taken out of personal interest or because of a hobby, have become a forum for science learning. Citizen science initiatives are considered programs because they often include structured and ongoing activities.

Venue

Chemistry communication takes place in many venues. Each venue has benefits and limitations that affect every aspect of the event, from design to delivery to evaluation.

Many events take place in spaces that are designed for other purposes, such as shopping malls, libraries, community centers, pubs, coffee shops, and the meeting spaces of social organizations or clubs (e.g., Rotary Club, Boys & Girls Club). In these venues, the physical conditions that can affect a chemistry event—particularly space and ventilation—are as variable as the venues themselves.

Some venues are intentionally designed to support science learning (NRC, 2009). These include museums of science and technology, science and nature centers, and zoos and aquariums. These designed spaces typically provide a range of exhibits and activities that require little guidance and allow for multiple points of entry (conceptually) to accommodate a wide variety of participants. Chemistry communication events held in designed spaces often use the existing exhibits, activities, and public spaces.

Finally, media stories, which are considered chemistry communication events, can be consumed anywhere: in designed spaces, in spaces used for other purposes, or in the spaces of everyday life—at home, on the bus, or in the park.

PARTICIPANTS

The term "general public" is often used to describe participants with nonscientific backgrounds. Neither in the literature nor among respondents to the landscape study, however, is the public considered monolithic, and the different needs and perspectives that can be present in a given set of participants are recognized. Thus, some social science scholars have adopted the term *publics* as a reminder that participants are almost always diverse subsets of society (McCallie et al., 2009). Dimensions were identified to classify these participants (e.g., Burns et al., 2003; Grunwald Associates and Education Development Center, 2013). As explained in the following section, participants can be described by demographics, by traits such as interest or investment, or by role in society.

General Publics

Many of the communication efforts examined in the landscape study were for general publics, that is, aimed at everyone. There was no qualification to participate, and no group of participants was targeted. However, variations in publics are important to consider when pondering the most likely consumers of chemistry communication. The "interested public" are the people who self-select to participate in events, even if they are not well informed about science. The "attentive public" are people who are already informed about and invested in science, such as science students who elect to participate in a community event. The "issue public" is the segment of the public that participates because of a particular concern, such as a local environmental or health-related topic (Hartings and Fahy, 2011).

Specific Demographic Groups

Many events target specific groups of people. For example, some are designed for children and families; they may target youth in kindergarten through eighth grade, adolescents or high school students, or families, which typically means children of all ages and their parents.

The landscape study uncovered many examples of events that targeted groups with other demographic characteristics, such as low-income families, seniors, and minorities. Experts interviewed in the study noted that efforts to broaden participation generally address a specific demographic that is underrepresented in chemistry or science.

Opinion Leaders and Decision Makers

In the literature and in the interviews of the landscape study, there were a few cases in which participants held certain positions, including mediators (individuals responsible for communicating science to others), decision makers (e.g., policy makers or leaders of institutions), and community leaders or other influential voices. The discussion related to communication with a goal of reaching such an audience, however, was not as rich or consistent as was the discussion related to communication for the other participants described in this section. These examples will not be discussed in detail as a result.

THE ROLE OF MEDIA AND TECHNOLOGY

The chemistry community shares information and engages with publics through a wide range of media channels, including print, radio, television, and online platforms. Members of the public are increasingly seeking their news from online sources (American Press Institute, 2014). Research has established that public opinions and attitudes about science can be shaped by information encountered in these different media platforms (Anderson et al., 2012; Scheufele, 2013; Yeo et al., 2014). Thus, the use of various types of media—and particularly online and social media—offers many opportunities for communicating chemistry.

Many chemistry demonstrations that cannot be done in an exhibit or event space can be shared using animations, simulations, or other technology. Technology allows chemists to present potentially hazardous demonstrations safely. The Chemical Heritage Foundation, for example, produced an interactive chemistry-set app that can be used on an iPad.[3] Uploading such demonstrations to popular media sources, such as YouTube, could broaden their reach.[4] Uploaded to the web, demonstrations can be viewed and reviewed by home users as suits their interests and needs.

A number of experts interviewed in the landscape study questioned whether the chemistry community is taking full advantage of technology and media for creating and disseminating communications. In addition, there is concern that visual aids may not be done well (Eilks et al., 2009). Online content runs into other problems as well. For example, a study published in *Science* found that the online "life" of content influences readers' perceptions of that content (Brossard and Scheufele, 2013). For example, negative or rude comments following a science blog post impact readers' responses to the post itself. This raises questions about how one shapes and uses online media environments for the most effective science communication, and how scientists view communicating online and how it affects public engagement (Besley, 2014).

Scientists' use of social media and its effectiveness for science communication are an active area of research, though most research focuses on science broadly rather than on chemistry. However, discipline-specific variations are beginning to emerge, for example, emerging research on how large, public events and announcements (such as Nobel Prize press releases) provide science communication opportunities and how the outcomes differ across disciplines (Baram-Tsabari, 2013).

The dissemination of information has changed dramatically in recent years with the increasingly active online communities. For example, research and events associated with informal science learning and science communication are regularly shared and discussed via Twitter under the hashtags #informalscience and #scicomm. Although the primary posters are

[3] See http://www.chemheritage.org/ChemCrafter [accessed February 2016] for more information.

[4] A January 2016 search of YouTube for the term "chem*demonstration" resulted in approximately 171,000 video results.

usually practitioners in those disciplines, the discussions are open and searchable by the public. Social media has also generated a broad interest in science and created excitement within the scientific community to share messages. Using Twitter once again as an example, the 2015 hashtags #IAmAScientistBecause and #IAmAChemistBecause provided motivation for individuals to share material with their contacts. Twitter is also a space where public commentary on science regularly occurs, whether as comments on social justice concerns in science or the sharing of information about articles and events (see, for example, #science). The study of the relationship between social media mentions and the consumption of traditional media is still in its infancy, but it is clear that social media platforms present an important tool in both engagement and dissemination, although the most effective ways to use them to achieve specific goals on specific topics are still under development.

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EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

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CHAPTER FOUR

Evidence-Based Research on Learning and Communication

Michael Faraday's 1827 lecture series on the chemical history of a candle, intended for nonscientist participants, is an early example of a chemist's desire to bring an understanding of chemistry to the general public.[1] The 2011 observance of an International Year of Chemistry, which was planned to excite young people about chemistry and raise awareness of the field's vital role in many issues, is a more recent example. Both examples reflect the goals for communication with the public that are discussed in this report.[2]

A growing body of evidence indicates that people do learn about science outside of school, in a wide range of informal, free-choice settings, and that these experiences are an increasingly important way for the public to learn (Falk and Dierking, 2010; NRC, 2009). However, these educational opportunities vary so much in terms of who provides them, venue, learning goals, content, and approach that assessing them and their effects has been difficult. The committee researched this sort of education, hoping to identify goals to improve it.

The committee explored several areas: The literature on learning science in informal settings includes findings from the science of learning and relevant research on classroom teaching and learning. Research on communications encompasses several fields. The commissioned landscape study provided data specific to chemistry. A thorough review of the relevant research was beyond the project's scope, but the report summarizes highlights from education and communications research, discusses particular challenges for chemistry, and identifies ideas for improving communication in chemistry.

INSIGHTS FROM RESEARCH ON INFORMAL SCIENCE LEARNING

A 2009 National Research Council (NRC) report, *Learning Science in Informal Environments,* surveyed the research on informal science education and is an invaluable starting point for insights into communicating chemistry in informal settings. The report gathers research from the fields of developmental and cognitive science, science education, museum research

[1] For a brief discussion of Faraday and the lectures, see Halsall (1998).
[2] See http://www.chemistry2011.org [accessed May 2014] for more information.

and evaluation, social science, and the science disciplines. It provides insight relevant to the venues in which people learn science outside of school, the nature of this learning, and ways it might be improved (NRC, 2009). Also invaluable is the follow-up report, *Surrounded by Science: Learning Science in Informal Environments* (NRC, 2010), which translates the findings in the 2009 report into concrete examples of effective approaches for practitioners in informal science settings, such as media, libraries, after-school programs, museums, aquariums, and zoos.

The 2009 NRC report characterizes informal science learning as predominantly "learner-motivated, guided by learner interests, voluntary, personal, ongoing, contextually relevant, collaborative, nonlinear, and open-ended" (NRC, 2009, p. 11). This description encompasses a wide range of activities that may take place at home or in public spaces of many kinds. The report notes that the research relevant to this kind of learning includes the study of institutions and the history of public learning (history and sociology); the study of how learning takes place and what promotes it (neuropsychology, psychology, education, and anthropology); and the study of design and other factors that affect visitors' experiences in informal learning settings, such as museums, zoos, and libraries. It also includes the study of audience responses to media stories about science. A significant base of knowledge about informal learning has developed through nonacademic research, such as the analysis of visitors' behavior and opinions or other market research approaches. Front-end, formative, and summative evaluation (see Chapter 5) have been used for years in exhibit development in museums and also inform this report.

More recently, there have been increased efforts to measure the results of informal education, to support decisions about the resources they require. At the same time, new technologies continue to expand the possibilities for informal learning, but also for the dissemination of misinformation, which increases the challenge to consumers seeking to understand the science. It has not been easy for researchers of informal learning to keep up with fast-paced developments or to track the relevant research from other social science disicplines.

Because there are many types of research relevant to informal science learning and many types of such learning, the 2009 report explores several ways to frame the landscape. These frameworks complement one another, and they are summarized in the following because they encompass the findings that are most relevant for the committee's task to develop a framework for communicating chemistry and to identify key areas for future research.

An Ecological Framework for Understanding Learning

The 2009 NRC report describes "An Ecological Framework for Learning Across Places and Pursuits" (NRC, 2009, pp. 31-41). The framework is based on insights from three fields: cognitive science, behavioral psychology, and sociocultural research on the factors that influence development and learning. Drawing on these fields, the report's authors stress the importance of attending to "three cross-cutting aspects of learning that are evident in all learning processes: people, places, and cultures" (NRC, 2009, pp. 31-32).

Ecologic, as defined in that report, refers to the relationships between individuals and their physical and social environments with particular attention to relationships that support learning. Just as biological systems can be understood as complex interactions between multiple natural forces, so can learning be understood as the complex interactions of multifaceted sociocultural contexts. In addition, the authors emphasize that learning about science and the practice of science happens naturally throughout the life span, and that this sort of learning is "inherently cultural" (NRC, 2009, p. 42). Thus, scientists who engage in informal learning activities should think about what people already know and their interests, concerns, and motivations for participating in an informal science learning event.

The 2009 NRC report also notes that for participants to identify with the scientists, participants must gain an understanding of the ways scientists approach their work and of the reality that scientific knowledge "is continually being extended, refined, and revised by the community of scientists" (p. 42). Scientists must understand the cultural norms and modes of expression of science in general and of their particular disciplines. The experiences and perspectives that individuals bring to science will shape their inquiry and their understanding. The ecological approach is useful in considering how to develop informal learning opportunities to meet the needs of participants by incorporating cultural experiences and everyday language, as well as by engaging participants in development, implementation, and other roles.

Goals for Informal Learning

Another model of the landscape of informal learning considers the learning goals that are pursued, which overlap with but also differ from goals for school-based science learning. For example, informal learners are motivated by their work and leisure activities to seek out new skills and information throughout their lives, and they respond to opportunities they encounter in social and public settings. The authors identify six interrelated strands, or dimensions of learning, that characterize informal learning, noting that learning can occur across individual or multiple strands. All six need not be engaged for learning to occur. The strands are presented here along with guidance on how to develop events that promote learning across them.

The authors propose that learners who engage successfully with science in informal environments may do the following (NRC, 2009, p. 43):

- Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.
- Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

- Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.
- Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.
- Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.
- Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.

The six strands provide a structure for understanding how people of different ages build on their experiences to learn science. The strands are not unique to informal environments but might also occur in formal education environments. However, informal environments, the report notes, are designed to encourage learners to explore and to satisfy their curiosity without performance expectations. In such settings, learners are likely to experience positive emotions such as excitement, wonder, and surprise, and also to pursue learning that is meaningful to them—both factors that are associated with learning and with retaining what is learned (NRC, 2009).

Informal learning offers an opportunity to ignite enthusiasm about chemistry, and the 2010 NRC report identifies strategies that take advantage of the way emotional responses can stimulate learning (NRC, 2010). For example, one model developed for the design of museum exhibits suggests that they should have six elements (NRC, 2010, p. 83):

- Curiosity—the visitor is surprised and intrigued,
- Confidence—the visitor has a sense of competence,
- Challenge—the visitor perceives that there is something to work toward,
- Control—the visitor has a sense of self-determination and control,
- Play—the visitor experiences sensory enjoyment and playfulness, and
- Communication—the visitor engages in meaningful social interaction.

The 2010 report provides detailed descriptions of activities that engage informal learners in many ways, highlighting the value of interactivity, opportunities for long-term relationships with science activities, and connecting scientific work to everyday life or to environmental and other social issues.

Strand 2, for chemistry, would include fundamentals such as the structure of atoms and properties of matter, as well as areas of application, such as cycles of matter and energy transfer in ecosystems. Research suggests that many of these concepts can be difficult for nonspecialist participants, an issue we discuss in greater detail below. Hands-on informal learning activities, such as making slime or playing with magic sand,[3] are often used to introduce young children to chemistry and Strand 3, to manipulate, test, and in other ways explore the natural and physical world. Strand 4, reflecting on science as a way of knowing, may be more effective for reaching adult participants and would encompass learners' awareness of their own process for learning. It would also include their experiences with the chemistry of everyday life, as observed in food and cooking, health and medicine, gardening and agriculture, and use of household products such as cosmetics or cleaners. Strands 3 and 4 both reflect the importance of considering what is relevant and accessible to the participants. For both children and adults, learning about ways of knowing in chemistry would encompass not only how chemists do their work but also how engineering relates to the work of chemistry.[4]

One way to address Strand 5 is through public participation in scientific research, sometimes called citizen science. This participation may be long term, such as at summer camp or after-school programs, or in cases when children or adults contribute to actual research over time. Such events foster knowledge of the process of science, improve understanding of the relevance of science to everyday life and social issues, and develop relationships between scientists and the public (Grunwald Associates and Education Development Center, 2013). Scientific events in which the public can be involved include (Bonney et al., 2009, p. 11)

- "choosing or defining questions for study;
- gathering information and resources;
- developing explanations (hypotheses) about possible answers to questions;
- designing data collection methodologies (both experimental and observational);
- collecting or analyzing data;
- interpreting data and drawing conclusions;
- disseminating conclusions; and
- discussing results and asking new questions."

Such events contribute to development along Strand 6 as well. Encouraging individuals to develop a sense of identity as a scientist or chemist is important not only for workforce development but also for helping all learners engage in critical, science-based thinking about their activities and world.

At present, there may not be adequate opportunities for public involvement in chemistry

[3] For examples, see the National Science Digital Library's informal educational resource database at http://www.howtosmile.org/content/teaching-chemistry-ideas [accessed May 2014], which provides demonstrations, exhibits, lab activities, games, lesson plans, models, and simulations with learning times ranging from under 5 minutes to 4 weeks.

[4] The National Academy of Engineering and NRC report titled *Technically Speaking* (NAE and NRC, 2002) notes that most people view technology as referring primarily to artifacts, such as computers and software or vehicles, and do not recognize technology and engineering as fields separate from the science disciplines. For the public, the term "chemistry" suggests not only the academic discipline but also all of its technological applications, such as the development of pesticides or other products.

activities that are rich and varied enough to support the development described in the six strands. In two polls conducted by Carlton Research Company for Research!America in May 2010 and March 2011, a substantial percentage of respondents said that they could not name a living scientist. A 1990 survey of science museums and science centers found that fewer than 30 percent had chemistry exhibits (Zare, 1996), and, more recently, research showed that chemistry continues to be one of the least represented disciplines in science museums (Silberman et al., 2004).

Environments for Informal Learning

The 2009 NRC report identified the three primary settings in which informal science learning takes place as a way to consider the characteristics that make it effective in different circumstances.

- **Everyday and family life:** People learn throughout their lives while participating in the activities of daily life, such as hobbies, outdoor excursions, technology use, or meal planning and preparation. People naturally develop expertise in areas that are important to them. These experiences cannot substitute for more structured opportunities but can be valuable in sparking interest in science and complementing learning that takes place elsewhere.
- **Designed environments:** Sites that are designed to enhance learning include science museums, zoos, nature centers, and visitor centers. These sites are designed to serve visitors who are there by choice and to allow them to pursue their own interests. Most of the learning is expected to be short in duration, though some long-term effects may occur. Growing attention is on ways to build on such short experiences. Different designed environments, such as museums and online media, may be linked if they share science learning goals, and this can facilitate learning along more of the strands for participants.
- **Programs:** Programs designed for children and adults include after-school programs, adult learning and continuing education programs, programs in retirement communities or nursing homes, and learning vacations. Like events offered in designed spaces, such programs primarily serve people who choose to participate, and many are intended to benefit people in need of support, such as disadvantaged children. These programs have not been as thoroughly researched as other areas of informal learning but hold potential, particularly for out-of-school programming for young people and for serving an aging population.

The 2009 NRC report also identified "media" as a crosscutting theme. Media activities occur in all venues, with newspapers, magazines, websites, television shows, radio shows, podcasts, and more being used both casually and purposefully at home, in designed spaces, and in youth and adult programming. These media activities include journalism focused on "the news" and entertainment-focused media like *Breaking Bad, Mythbusters,* and video games, among others.

Assessing Outcomes

The diverse universe of informal science learning yields diverse outcomes, and thus there are multiple ways to assess them. *Learning Science in Informal Environments* (NRC, 2009) notes that learning outcomes include not only gains in content knowledge and conceptual understanding but also changes in the learners' perceptions about and attitudes toward science and science learning. Some informal learning is very short term, but some can have lasting impact. Learning may occur on a group or even a community level. For example, a science class may improve its capacity to collaborate in solving a science problem as a result of a field trip, or a community might build its capacity to pursue an environmental goal, such as recycling, as a result of educational programming.

Valid assessment of results, the authors note, needs to reflect the goals of a learning opportunity and must not undermine those goals, for example by imposing stressful performance expectations on an experience that is designed to be fun. Accurately identifying the skills, knowledge, and concepts that event participants could develop is complicated, in part because the participants bring diverse qualities to the event—qualities generally unknown by the event's planners. Informal science learning is intended to be responsive to a learner's interests and capabilities, and thus the outcomes may be unexpected and surprising.

Insights from Research on Communication

Many social science disciplines contribute to understanding communication, including psychology, sociology, political science, risk communication, media studies, public relations, decision science, social marketing research, and the science of communication itself. A comprehensive review of the relevant literature from these diverse fields is beyond the scope of this report, but much valuable work has been done to apply communications research to science communication, education, and policy.[5] The committee benefited from work on the science of science communication, which has begun to synthesize insights from various fields. Two of the Sackler Colloquia of the National Academy of Sciences provided a valuable overview of research and perspectives on the science of science communication (NAS, 2013; NRC, 2014b). The committee also explored data on public perceptions of science, scientists, and

[5] For overviews of the field of public communication in science see Bauer and Howard (2012), Bauer et al. (2007), Bucchi and Trench (2014), and Suerdem et al. (2013).

BOX 4-1
Four Communication Tasks

Task 1: Identify the science most relevant to the decisions people face.
Task 2: Determine what people already know.
Task 3: Design communications to fill the critical gaps (between what people know and need to know).
Task 4: Evaluate the adequacy of those communications.

SOURCE: Fischoff, 2013, p. 14034.

science institutions for insights to help bridge gaps between professional science and everyday communication.

Goals for Communication

The academic field of communication has not identified a set of formalized strands for practitioners. Rather, science communication scholarship acknowledges the wide range of goals of practitioners, from science learning to providing science information to addressing societal challenges to building a stronger science-public interface. For example, the goal of a chemistry communication event could be to build trust with participants, to stimulate a discussion about the chemistry of cooking and learn from participants what interests them, or to build media attention about an area of advancing research.

Baruch Fischoff, a professor of social and decision sciences, describes four tasks for those communicating about science (see Box 4-1). Fischoff emphasizes that communication events that do not reflect the needs, interests, and values of the participants will be unlikely to engage them as intended, if at all. In addition, communication events should be evaluated to avoid assumptions about why an event was unsuccessful, and to avoid perpetuating myths such as that the public does not understand science (Fischoff, 2013).

Public Engagement

For successful public engagement, a chemist needs more than the content to be shared and an event plan. In designing an activity, a communicator must be explicit about what will be addressed, particularly at the conceptual level, as this will frame the activity and aid in the creation of appropriate materials to support the experience (Hmelo-Silver et al., 2007; Lidar et al., 2006; Nathan et al., 2007; Rappoport and Ashkenazi, 2008; Stieff et al., 2013). However, relying on intuition about which messages or engagement mechanisms will be most effective is not likely to succeed (NRC, 2014a). Science communicators must understand what participants hope to gain from the experience and what they bring to it. Participants might, for example, be filling a gap in their understanding of the science topic, might have misconceptions about it, or might have a need for specific information (Fischoff, 2013; NRC, 2009, 2014a).

Science communicators should understand the ideas, beliefs, and perspectives that participants bring, especially with a topic that raises social or political issues about which people disagree (Fischoff, 2013; NRC, 2009, 2014a). In informal settings, where scientists may not know the participants or have an opportunity to build a relationship, understanding what participants bring may be more difficult than in a formal classroom (NRC, 2009). There are ways to elicit a sense of participants' understanding, though strategies for classroom teachers have been studied more than strategies for informal settings (e.g., Ambrose et al., 2010; Fisher, 2004). Research does show that giving participants the opportunity to exercise control over the goals of a particular experience helps them learn (Bandura, 1986, 1997).

Environments for Communication

The scientific community (individuals and their institutions) primarily communicates with colleagues about its work through peer-reviewed journal publications (Harley, 2013). Many scientists also share their research with journalists, who publish news articles about it (Peters, 2013). However, research publications and news articles do not enable scientists to engage with the public. In addition, the range of goals of communicating science with the public, from sharing excitement about science to building trust to informing policy decisions, necessitates a range of communication tools and strategies. There are many communication technologies through which science content can be accessed—science programming on television, newspaper and magazine articles, science fiction writing, and the Internet (e.g., Wikipedia), to name a few—and interactive technology is now omnipresent in designed spaces.

The Internet, in particular, is creating more opportunity for scientists to interact with participants. There are an increasing number of online communities devoted to science interests (Peters et al., 2014). For example, Reddit[6] is a popular moderated online forum in which a chemist can participate in an Ask Me Anything—scheduled forum time to answer questions and interact with people interested in science. Another example is #scistuchat, an informal but themed monthly Twitter discussion, created by a high school science teacher so that students can interact with scientists outside of school.[7] Another popular online venue is ResearchBlogging.org, a website where scientists post information about peer-reviewed work

[6] See https://www.reddit.com/r/science [accessed February 2016] for more information.
[7] See http://www.scistuchat.com [accessed February 2016] for more information.

for discussion both with peers and members of the public (Shema et al., 2012). Evidence suggests that social media may amplify a researcher's scientific impact (Liang et al., 2014). However, very little research has been published on scientists' attitudes toward and use of online and social media, or the effectiveness of public engagement on science topics through social media (SCIMEP, 2015).

LINKING INFORMAL SCIENCE LEARNING AND COMMUNICATION

A Communication Model for Informal Learning Settings

There are many models that describe objectives for communicators, many of which share features. The committee invited Dr. Katherine Rowan to summarize key implications of communications research for informal science education, and she presented one such model, called CAUSE, to organize these implications. This model is described here as an example of the objectives often called for in the communications literature. The acronym CAUSE represents five objectives for communicators, who need to

- earn the Confidence of those with whom they are communicating;
- create Awareness of benefits or dangers;
- deepen the Understanding;
- help participants gain Satisfaction with possible solutions; and
- support the Enactment of solutions.

Dr. Rowan explained that to earn someone's confidence, research indicates that it is important to listen to their views and concerns, show them respect, and create conditions that encourage them to ask questions. To deepen people's understanding, communications experts find it necessary to explain ideas that are often misunderstood, which may include terms (e.g., polymer), complexities that are difficult to envision (e.g., how carbon dioxide traps heat), or counterintuitive concepts (e.g., how a naturally occurring gas such as carbon dioxide can be harmful). When explaining the meanings of key terms, communicators endeavor to convey what the terms do not mean as well as what they do mean—by pointing out, for example, that "chemical" does not mean artificial or human made. It is also useful to provide a range of examples: for example, polymers are giant molecules that can be natural (rubber, starch, or DNA) or made by scientists (nylon or polyethylene).

Another strategy to deepen a participant's understanding is to use analogies or visual representations. A familiar analogy used to explain how carbon dioxide (CO_2) traps heat on Earth, for example, is the greenhouse: CO_2 allows light energy from the sun to enter Earth's atmosphere, and, much as a greenhouse does, it traps some of the heat that subsequently

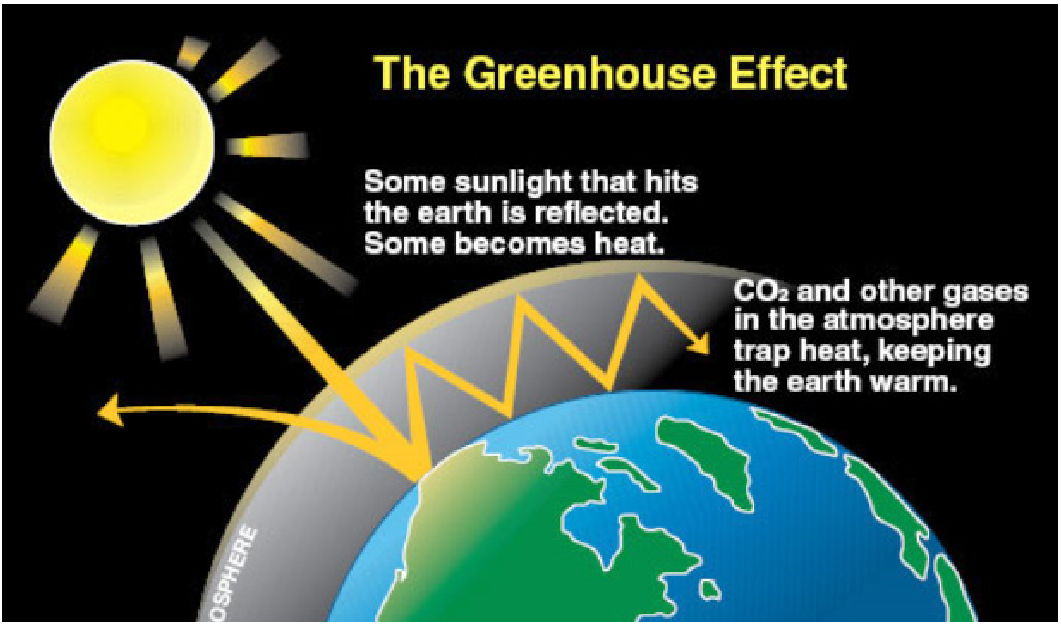

FIGURE 4-1 A visual representation of the greenhouse effect.
SOURCE: State of Washington, Department of Ecology: http://www.ecy.wa.gov/climatechange/FAQ.htm [accessed June 12, 2015].

returns from Earth. When presenting to the committee, Dr. Rowan used Figure 4-1 as an illustration of this concept.

It is also important for communicators to consider "lay theories"—possibly erroneous understandings that people have about familiar aspects of life, such as weather or disease. The communicator can acknowledge the apparent reasonableness of a lay theory, noting, for example, that "most people have not seen molecules so it is understandable if they wonder whether they exist." The next step is to generate dissatisfaction with the lay theory and then explain the current scientific consensus.

Public Perceptions of Science and Scientists

The challenge of conveying science in informal settings may be complicated by public perceptions of scientists and their research institutions. A 2012 survey conducted by the National Science Board (NSB) showed that the American public has a high regard for scientists in general. However, less than half of Americans reported that they have an excellent or good understanding of how scientists investigate and analyze phenomena (NSB, 2014; see also results from the Pew Research Center, 2013). For example, respondents to the 2012 NSB survey displayed limited understanding of scientific experimentation and the concept of controlling for variables. Data from the General Social Survey (GSS)[8] on public confidence in institutions demonstrates that public confidence in the scientific community has remained stable since 1973 and is consistently greater than American confidence in 10 of the other 12 institutions included in the survey, including the Supreme Court, education, and organized religion (Smith and Son, 2013). However, on average the percentage of the public with "only some" or "hardly any" confidence in the scientific community is greater than 50 percent.

Institutional affiliations may influence how publics perceive science and scientists. For example, a public opinion study in Australia found that members of the public are less supportive of stem cell research if it is conducted within a private company than if the research is conducted by a publicly funded (e.g., academic) institution (Critchley, 2008). Similarly, university scientists are the most trusted source of information on the risks and benefits of nanotechnology, compared with industry scientists, regulatory agencies, environmental organizations, and other groups that communicate about science (Scheufele et al., 2009). That finding is particularly important for chemists who work in industry; participant reactions to industry-affiliated chemists may be due to their perceptions of chemical companies rather than the field of chemistry.

Social identity (e.g., culture, political ideology, education level, and religious beliefs) influences public perceptions of science and scientists, perceptions which can be dynamic, and the influence of social identity can vary from topic to topic (Kahan et al., 2011). For example, highly religious and conservative Americans are the most concerned about the risks of synthetic biology (Kahan et al., 2009) yet the least concerned about the risks of global warming (Kahan et al., 2012). More than half of the respondents to a 2009 survey conducted by the Pew Research Center believe that science and religion are often in conflict (Pew Research Center, 2009). Social identity plays a role in perceptions of a wide range of topics such as hydraulic fracturing (Boudet et al., 2014), nanotechnology (Scheufele et al., 2009), and stem cell research (Nisbet and Markowitz, 2014), among others.

Research also suggests that responses to science information and ideas about which authorities to trust depend in part on *confirmation bias,* the cognitive phenomenon that people are predisposed to accept information that accords with what they already believe and to be more skeptical of information or sources that challenge their beliefs, and *motivated reasoning,* an unconscious tendency to process information in a way that fits a preconceived outcome or goal (Haidt, 2013; Kahan et al., 2011; Kunda, 1990; Scheufele, 2006).

Because of the breadth and complexity of factors that influence people's perceptions of science, building trust between chemists and participants is critical for science communication and learning in informal settings. Although there is no universal definition of trust, public relations and communications scholars generally agree that trust involves people's confidence

[8] A social science survey of American attitudes, behaviors, and attributes, the GSS is conducted by the independent research organization NORC at the University of Chicago, and has been monitoring American society since 1972.

in and willingness to open themselves to one another (Chryssochoidis et al., 2009; Hon and Grunig, 1999; Resnick, 2011). In the *Guidelines for Measuring Relationships in Public Relations,* trust is described as having three primary dimensions: *confidence,* the belief that an entity has the ability to do what they say they will do; *integrity,* the belief that an entity is fair and just; and *dependability,* the belief that an entity will do what they say (Hon and Grunig, 1999). In addition, whether or not someone has trust in someone or something is influenced by perception of the information, of the information source (e.g., scientists or science institutions), and of risk and by the person's own personality and sociocultural characteristics (Chryssochoidis et al., 2009).

Regarding the information source, research on social relationships demonstrates that people are most likely to trust those they believe are competent (perception of capability) and warm (perception of intent; Fiske and Dupree, 2014), two characteristics that reflect the three dimensions of trust described above. People often have preconceptions about how competent or warm different groups are. Scientists, researchers, and engineers are viewed consistently as highly competent but in the middle range for warmth. They fall just within a clustered group that elicits mixed emotions of admiration and resentment, and so their intentions may not always be trusted. For example, survey respondents recruited through Amazon's Mechanical Turk system were asked about climate scientists and answered that "scientists might lie about statistics, complicate simple stories, feel themselves superior to nonscientists, pursue a liberal agenda, or provoke and hurt big corporations," or that they might slant their research to obtain funding (NRC, 2014b, p. 10). Hence, building trust requires not just warmth but attention to research integrity, openness about political, financial, institutional or other affiliations, and transparency about the motivations for communicating about chemistry.

Regarding information and risk, scientists are respected for their role in education and protecting the environment and may be most trusted when they communicate about scientific information, as opposed to policy proposals (NRC, 2014b). The types of science that are most likely to seem relevant and interesting to participants, however, are likely to relate to challenging policy questions. And, scientists face the challenge of accurately and clearly communicating the degree of uncertainty associated with results (NRC, 2014b). The nature and degree of uncertainty might be important when considering policy options, but complete understanding might require a sophisticated understanding of the scientific methods in question, and science communicators are sometimes cautious, for fear of unintentionally creating misunderstanding.

Web-Based Communication

A significant amount of informal science learning takes place through broadcast, print, and digital media, and the possibilities in this area are evolving quickly. Unfortunately, research on science communication in informal environments has not kept pace with the rapid rise of online and social media as a means of communication and learning about science, including chemistry. Educational television has been the most studied of these media and has been found effective in supporting learning (NRC, 2009). However, the Internet is now the primary source of information about science and technology for most Americans (NSB, 2014). Because Web-based platforms have become such a prevalent means of informal science communication, the committee asked Ayelet Baram-Tsabari, a professor of biology education and science communication at Technion–Israel Institute of Technology, to summarize the recent research. Baram-Tsabari explained that in Western countries, the Internet has become the primary source of science-related information, with 60 percent of the U.S. public citing it as their main source for information about science issues. The majority of Americans who use the Internet rely on nontraditional online sources—only 12 percent use web sources developed by traditional print newspapers and magazines (Baram-Tsabari and Lewenstein, 2013).

The Internet is widely accessible but has disadvantages. Research has indicated that reading on digital screens is inferior to reading paper materials; readers prefer paper and have improved metacognitive performance when they read on paper (Ackerman and Goldsmith, 2011). The divide between those who do and do not have access to the Internet affects access to science information. And, among those who have access, there is significant variability in the skills needed to locate information (Segev, 2010) and to evaluate the quality of the information and the source (Wiley et al., 2009). On the other hand, frequent Internet users report more positive attitudes toward science than people who are offline (Brossard and Scheufele, 2013), and Internet use can compensate for educational disparities (Cacciatore et al., 2014).

Researchers have used data mining to explore the interests and information needs that Internet users demonstrate through their search queries (e.g., Anderson et al., 2010; Choi and Varian, 2009; Ginsberg et al., 2009; Segev and Baram-Tsabari, 2012). This research reveals patterns, such as increased interest in a particular science and technology topic in the wake of events covered in the media that concern the topic. Such interest tends to wane over time, however. Baram-Tsabari suggests that the effectiveness of a teachable moment presented by a public event depends on how well the science community responds to and takes advantage of the opportunity (Baram-Tsabari and Osborne, 2015).

Web-based resources have become increasingly interactive: wikis, blogs, video sharing, massive open online courses, and social networking sites, for example, are all highly interactive resources. Such resources allow nontechnical users to participate in science in new ways. Comment forums can enable scientists and policy makers to learn about the concerns, sources of information, and general knowledge participants have about science topics with social and political ramifications, such as nanotechnology or climate change. Some sites allow participants to ask scientists questions in real time. However, Baram-Tsabari reported that scientists prefer other forms of communication, such as writing articles, to Web-based forms such as managing websites or participating in social media (Baram-Tsabari and Lewenstein, 2013). The attitudes of scientists toward engagement online, how they perceive the public who participate in online interactions, and other critical factors that will frame online science communication are still largely unstudied (Besley, 2013).

CHALLENGES FOR CHEMISTRY

As stated previously, it is important to present science in a context relevant to participants. Finding this relevance for chemistry, however, is challenging because not much research targets public perceptions of chemists and chemistry or the effectiveness of chemistry communication events in informal settings. In a 2000 telephone survey commissioned by the American Chemical Society, approximately one-third of those surveyed had an unfavorable view of the chemical industry, which received the least favorable ratings of 10 science-related industries (NSB, 2002). Reasons included the potential negative environmental and health impacts of chemicals and a view of the industry as one that pollutes the environment and does not communicate with consumers. However, the majority of those surveyed had positive views of chemistry as a profession, particularly in basic chemical research, and 60 percent said that chemicals make everyday life better. This suggests that professional affiliations (e.g., the chemical industry) have a strong influence on public perception of chemists.

Recently, a survey by the Royal Society of Chemistry (RSC) provided positive news regarding public perception of chemistry in the United Kingdom and highlighted differences between the expectations of chemists (who believed public perception would be mostly negative) and the actual public perception (generally positive; RSC, 2015). Comparing such data across surveys and countries is challenging because of cultural, political, and other differences that influence perception (Besley, 2013). Nevertheless, the RSC report is a reminder to chemists considering public communication to consider one's own assumptions about participants before designing an event.

As previously described, trust is a critical factor for learning and public engagement. Research integrity, the credibility of the scientist and content, and institutional or other affiliations affect trust. Thus, the quality of the research being shared, the warmth and competence of the scientist, and transparency about affiliations and motivations for communicating should be considered when planning any event.

Insights from Chemistry Education

Research on student experiences with chemistry in the classroom informs the discussion of participant perception, which often originates in the classroom. Although formal education environments are different than informal ones, there is little research on chemistry in informal environments. However, relevant lessons from formal chemistry education can be used to aid chemists interested in designing public activities to communicate chemistry.

Many students struggle with chemistry. Research suggests that the abstract nature of molecular interactions, difficulty relating submicroscopic structures and macroscopic effects, and a lack of fluency with the tools of representation and symbolism in the field are key reasons. These difficulties can form fundamental conceptual barriers to understanding chemistry's real-world applications that carry forward from early classroom experiences to later life and result in lifelong attitudes about chemistry.

The capacity to think in abstract terms about chemical phenomena is not intuitive—it is developed through experience and training (Erduran et al., 2006). Proficiency in chemistry requires scientists to be fluent in the relationships between chemical phenomena at both visible and submicroscopic levels. Chemists rely on visualizations to understand the underlying processes, solve problems, and communicate ideas, and there is ample evidence that many students find this kind of thinking difficult (Ealy, 1999, 2004; Gilbert, 2005; Hinze et al., 2013; Kozma and Russell, 1997; Mathewson, 1999; Stieff et al., 2011; Wu and Shah, 2004).

These visualizations represent the spatial relationships in atomic and molecular structure through which chemists explain chemical and physical properties that can be observed. While imperfect, they represent chemists' understanding of reality in a way that allows them to communicate easily (within the chemical community) and to advance their work. Chemists are usually aware of the limitations of their models but rarely articulate these issues. For example, although all molecules are three-dimensional, chemists usually represent them with two-dimensional diagrams. Whereas chemists perceive how these diagrams imply three-dimensional relationships, the uninitiated can mistakenly infer that molecules themselves are two-dimensional. Chemists themselves sometimes overlook the limitations of visual representations (Haidar, 1997).

Research examines how people develop mental models of information they know, even if the information is incomplete, suggesting it is relatively easy for a novice to be led astray by a seemingly simple representation (NRC, 2014b). Learners also have difficulty with abstract concepts that are presented without context, such as relevance to everyday life, that helps the learners relate a concept to knowledge they already have (Tobias, 1990). Chemists' reliance on representing abstract concepts in a visual language that is unfamiliar to nonexperts adds to the challenge of communicating chemistry to nonexpert publics and points again to the value of establishing the relationship between teaching objectives and real-world applications.

Because chemistry knowledge is represented on macroscopic, submicroscopic, and symbolic levels, full understanding requires coordination across these levels, linking the symbols to the submicroscopic interactions and to the macroscopic outcomes. Learning environments in which all three levels are presented simultaneously and are explicitly related to each other are likely to support learners in accomplishing this coordination (Johnstone, 1993; Kozma and Russell, 1997, 2005; Kozma et al., 1996; Stieff, 2005; Stieff and McCombs, 2006; Stieff and Wilensky, 2003; Stieff et al., 2011). Thus, the use of multiple, linked representations to communicate a single concept may be more likely to help informal learners grasp it.

Chemistry is frequently concerned with the transformation of spatial objects over time (e.g., molecular vibrations in three dimensions), which is not directly perceptible. Understanding spatiotemporal dynamics and other complex processes can be easier when they are represented both visually and verbally (Clark and Paivio, 1991; Mayer, 2001; Newcombe and Stieff, 2012; Paivio, 1986). Animations and simulations can represent dynamic chemistry concepts, but experts evaluate these visual representations differently than novices do. Novices may not recognize which features they should attend to because they lack familiarity with the underlying conceptual framework (Kombartzky et al., 2010; Mason et al., 2013; Plass et al., 2009, 2010; Stieff et al., 2011). Visual representations are likely to be most useful to novice learners when they use a minimum of information to communicate an idea (Kozhevnikov et al., 2006; Kozma and Russell, 1997; Ruetenik et al., 2011; Stieff and McCombs, 2006). Animations and simulations are useful in informal environments so long as they display limited amounts of information, promote interactive engagement, and are used together with activities that guide learner attention (Stieff and Ryan, 2014).

Evidence of the challenge that chemistry presents is apparent in both secondary school and undergraduate chemistry classrooms (Stieff and Wilensky, 2003) and can be observed even among advanced undergraduate students. Research has shown, for example, that individuals have trouble recognizing that equilibrium is a dynamic process despite years of formal schooling in chemistry. In addition, communicators may encounter conceptual challenges. For example, a fundamental concept in chemistry is the assumption that if two substances are identical in chemical composition and structure on the submicroscopic level, they will have the same properties on the macroscopic level. The converse is not true: chemists do not assume that two macroscopically identical substances will share the same chemical composition and structure. Nonexperts, however, are prone to make this error, thinking, for example, that "copper atoms are shiny because copper wire is shiny" or "two beakers of transparent liquid both contain water molecules."

Unfortunately, many students' school experiences contribute to misconceptions of chemistry concepts. The Grunwald Associates study suggests that chemistry is not well represented in K-12 education and that it is not taught in ways that promote broad understanding and recognition of real-world applications (Grunwald Associates and Education Development Center, 2013). Traditional instructional methods often focus on molecular-level interactions and treat everyday observations as enrichment activities, though students at all academic levels tend to be more interested in topics with direct relevance to their experiences (Glynn et al., 2007). In addition, negative interactions with science instructors and poor performance discourage many students and may contribute to a perception that science belongs to an "elite" group of individuals (Chiarelott, 1987; Udo et al., 2004). Topics such as the chemistry of health or the environment and those that appear in the news, on television, or in movies (crime investigation is a prime example) help to engage students in the explanatory power of chemistry (Glynn et al., 2007).

Other fields have similar challenges. Biologists have difficulty explaining the effects of

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

bacteria on human health—a problem similar to that of chemists explaining phenomena that are not directly observable—yet the public has come to understand that bacteria impact human health. Also, chemistry is often embedded in topics that are seen as belonging in other fields, and some observers have noted that "there is no single idea that unites the field or common story about what it is and what it means" (Grunwald Associates and Education Development Center, 2013, p. 11). Because chemistry concepts that arise in informal learning settings are often presented in the context of topics in physics or biology, these opportunities do not necessarily bolster understanding of why chemistry is important.

PRINCIPLES FOR CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

A few ideas manifested themselves repeatedly in the work we examined and form the basis of a set of principles that can guide the development of effective informal chemistry communication opportunities. These principles provide the basis on which the practical framework in Part B is built.

Use knowledge of the participants to identify clear and specific goals and target outcomes for the chemistry communication experience.

Informal communication about chemistry is most likely to be effective if it meets the needs of the populations it is to serve. The chemistry communicator must have some knowledge of the likely participants to tailor the content and set goals. This knowledge must be integrated into a logical plan that suits the time and resources available. Science communicators should seek to understand the ideas, beliefs, and perspectives that participants bring and should take into account their values and level of knowledge. Engagement around social issues that people have strong opinions about can be a valuable opportunity to develop participants' awareness of what science contributes to understanding and potential solutions.

Use understanding of participants to make the experience engaging and positive.

Chemistry communication should be an opportunity for participants to become excited about phenomena that scientists explore and about scientists' methods. Activities that are fun, and that allow participants to engage and interact with the material, can enable them to see themselves as science learners. Learning about science happens naturally throughout life, and well-planned informal communication opportunities help people connect that learning with science concepts, retain the knowledge, and feel encouraged to seek more knowledge. Topics that link science with environmental and other social issues can provide an incentive to engage. To promote this kind of learning, communicators must incorporate the cultural experiences and everyday language that will be most familiar to participants.

Use the nature of the experience to engage participants.

Specific characteristics of an experience are likely to encourage participants to explore and satisfy their curiosity. Informal settings are easier to explore in, in part because performance expectations are not usually part of the experience but instead may be one outcome. Rather than being tested, participants should be encouraged to do things that scientists do: ask questions, observe phenomena, make models, develop and test hypotheses, examine data and evidence, draw conclusions, imagine and design practical implications, test and revise prototypes, discuss both potential positive and negative impacts of an innovation, and the like. Settings and program designs that encourage participants to think, play, and interact with one another, with the science communicator, and with the materials and content tend to generate the excitement, wonder, and surprise that make the science event meaningful. When such activities become long-term relationships with science (for example, when participants contribute to data collection or other citizen science efforts), the relationships build understanding of or appreciation for the scientific process and help people make connections between science and everyday life. Often, scientists gain from these relationships as well, for example, by learning from interactions with participants or by benefiting from the data participants collect.

Use strategies that are valuable for informal chemistry communication.

For many participants, the abstract nature of molecular interactions, difficulty with the relationship between submicroscopic structures and macroscopic effects, and a lack of fluency with the tools of representation and symbolism in the field can be obstacles to understanding and to an appreciation of chemistry's real-world applications. The use of multiple, linked representations to communicate a single concept may help participants grasp it. Analogies and visual representations, such as animations and simulations, are especially useful in helping novices understand abstract ideas and phenomena that cannot be directly observed. The fact that people learn throughout their lives while participating in the activities of daily life, such as hobbies, outdoor excursions, or cooking, is especially useful with chemistry, because informal learning opportunities can build on the expertise that people naturally develop in areas import to them.

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CHAPTER FIVE

Evaluation to Refine Goals and Demonstrate Effectiveness

Measure what is measurable, and make measurable what is not so.

—Galileo

Evaluation is required for creating effective communication. It is needed to determine audience needs and interests, to test communication approaches, and to evaluate impact.

—David Ucko, 2012

Many communication events are initiated because of a chemist's desire to increase public awareness, appreciation, or understanding of chemistry. How does the chemist know if such events are effective? Evaluation can determine effectiveness and can be performed to varying degrees. A chemist will first need to decide whether the best evaluation option for an event is a simple, one-time, on-site assessment of participant responses or a more in-depth, time-intensive programmatic assessment conducted by a third-party expert. Fortunately, there is a body of research on evaluation and many resources available to aid organizers in selecting an evaluation type based on their needs and in conducting the evaluation. This chapter provides an overview of the research on evaluation and guidance for performing evaluations in informal settings.[1] It addresses evaluation appropriate for large installations in museums as well as for small, one-time activities. The process of evaluation may seem overwhelming; however, although elements of an evaluation will be similar regardless of the event, the scope and intricacy of the evaluation will scale with the event complexity and with the goals of the chemistry communication event.

[1] This chapter draws extensively from *Communicating Chemistry in Informal Environments: Evaluating Chemistry Outreach Experiences* (Michalchik, 2013). As part of its formal information-gathering process, the committee commissioned this paper, which provides an extensive review of social science theory on evaluation for informal science learning.

BOX 5-1
The Three Stages of Evaluation

1. **Front-end evaluation:** Obtain and synthesize information about participants' interests, needs, knowledge, and motivations. Front-end evaluation should be conducted to help develop or modify goals and anticipated outcomes of a communication event.
2. **Formative evaluation:** Obtain participant feedback on the design, development, and implementation before or during a communication event. Formative evaluation enables the effectiveness of a communication event to be improved before the event has been fully carried out.
3. **Summative evaluation:** Determine if the communication event achieved its intended goals and outcomes. Summative evaluation provides evidence of whether the experience worked as intended for the participants and the organizer.

WHAT IS EVALUATION?

Evaluation is a set of techniques used to judge the effectiveness or quality of an event; improve its effectiveness; and inform decisions about its design, development, and implementation (NRC, 2010). Evaluation can occur before, during, and after an activity. Three stages of evaluation are front end, formative, and summative (Michalchik, 2013; Box 5-1).

WHY EVALUATE?

Evaluation, if begun at the outset of planning, can make communication events more effective at meeting their intended goals. As described by Michalchik (2013), evaluation enables chemists organizing an activity to learn about intended participants, receive advanced feedback about communication design, and determine whether the goals and outcomes are met. Widespread use of evaluation would help chemistry communication meet the four goals listed in Chapter 2 or other goals.

A well-designed evaluation typically improves the quality of an experience by helping better define goals, identify important milestones and indicators of success, and support ongoing improvements. The information generated during an evaluation is useful to others seeking to learn from their colleagues' experiences. In addition, evaluation can provide evidence of value to funders, potential partners, and other stakeholders. Reports from evaluations can also inform efforts to replicate or broaden the scale of a communication effort.

Evaluation provides valuable information to funders and other stakeholders that support communication. Funders may require evaluation. For example, the National Science Foundation (NSF) requires all proposals to its Advancing Informal Science Learning (AISL) program to include an evaluation plan and to demonstrate that a professional evaluator will be involved from the early stages in the project's conception. Specifically, the evaluation plan must do the following:

> [E]mphasize the coherence between the proposal goals and the evidence of meeting such goals. It must be appropriate to the type, scope, and scale of the proposed project. It is strongly encouraged that the plans include front end, formative, and remedial/iterative evaluation, as appropriate to achieving the projects' goals. (NSF, 2014, p. 10)

Beyond AISL, NSF requires that *all* grant proposals, including proposals for research in chemistry, describe the broader impacts of the research on society. As noted previously, some researchers meet this requirement by including communication events in the proposal, although they are not required to include an evaluation plan. Nevertheless, evaluation should be a part of every chemist's toolkit for communication, whether required or not, because it is helpful at each phase of designing and conducting communication. Although evaluation is often conducted by trained professionals using specialized techniques, anyone can use basic evaluative approaches to inform the design and development of communication activities and to learn about their impact.

OVERARCHING CONSIDERATIONS

The data described in Chapter 3 revealed that chemistry communication events in informal environments vary greatly in objectives, activities, content, and participants. Thus, evaluation plans can vary greatly in depth and scope, but efforts to evaluate even diverse activities follow an approach defined by research and by professional practice in the evaluation of informal science learning (Bonney et al., 2011; NRC, 2009). This section describes the elements of that approach and presents some guidelines for evaluation.

Evaluation planning should begin in parallel with defining the goals and desired outcomes of the communication event. This planning includes developing evaluation questions, indicators, and measures; selecting appropriate methods to gather information about the indicators; using the methods to gather, analyze, and interpret the data; and applying findings to inform the design or revision of a current event, or to inform the development of future events. Some steps of evaluation may seem daunting or excessive especially for chemists planning one-time communication activities on their own, but the requirements and scope of an evaluation will vary depending on the activity and often will not be arduous. Incorporating evaluation from the beginning can help the organizer identify clear goals. Understanding the

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

general principles of evaluation and using it can improve events, whether the organizer is an individual chemist or a chemistry department partnering with a science center on a large-scale communication event.

The most important consideration in developing an evaluation plan is how best to serve the needs of the communication event given the available time, budget, personnel, and other issues of capacity. Tailoring expectations of what can be accomplished in an evaluation is a critical and often challenging part of developing an evaluation. Efforts to follow a lockstep set of procedures or employ plug-and-play evaluation tools may lead to frustration if there is a lack of relevant data. Communication goals, evaluation plan, and selected outcome measurements must be aligned to conduct a meaningful evaluation of an experience.

DEVELOPING AN EVALUATION PLAN

Planning for evaluation is different from, but related to, planning the communication event itself. Evaluation planning integrates a clear understanding of the intent and context of the communication event with the purposes of the evaluation. When working with a professional evaluator, a preliminary step is to provide the evaluator with background information about the project to provide the necessary context for the evaluation work.

Project Goals and Outcomes

The first step in designing and evaluating an effective chemistry communication project is to specify its intended goals and outcomes. A project without clearly defined goals and anticipated outcomes cannot be evaluated. An approach used by professional evaluators is to describe in visual form a project's rationale using a *logic model* (Figure 5-1).

A logic model specifies the stages in a project to describe how the project works. It defines and shows the relationships between the project's inputs, activities, outputs, and outcomes as defined in Box 5-2. Although it may be relatively easy to specify the communication event (e.g., a hands-on chemistry experiment in a museum exhibit) and the desired output (e.g., a large percentage of museum visitors will choose to conduct the experiment), it can be more challenging to identify the desired outcomes—what the participants will get out of a given experience. In the logic model, the outcomes are often described as short term, occurring within a few years of the event; midterm, occurring 4 to 7 years after the activity; or long term, occurring many years after an event has commenced.

Communication events are often designed to encourage long-term impacts, such as future science participation or additional learning through subsequent experiences. They may also aim to achieve shorter-term outcomes. Although included in logic models, long-term outcomes are rarely measured because of their complexity and long time horizon (Bonney et al., 2011; NRC, 2009). However, some funders value evaluation approaches that can demon-

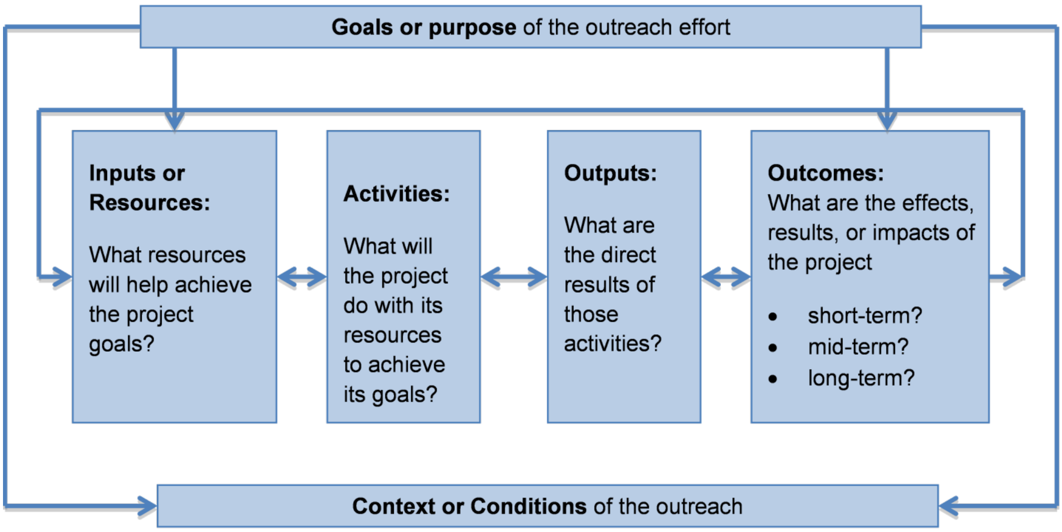

FIGURE 5-1 Basic logic model for evaluating chemistry communication experiences. The process of creating a logic model helps identify and define the inputs, activities, outputs, and outcomes of a communication event, which is especially useful if the project is complex.
SOURCE: Michalchik, 2013.

strate the long-term impact of science communication. For example, NSF requires that funding proposals for its AISL program include not only measures of learning outcomes for the target participants, but also the intended long-term impacts on science, technology, engineering, and mathematics (STEM) learning.

A logic model should be dynamic. Any element—inputs, activities, outputs, or outcomes—can change as the project develops. The changes should be reflected in the model. Logic models should also be based on careful alignment between the activities (the nature of the experience for participants), the outputs, and the expected outcomes. For example, if a project promotes playful exploration of materials and substances, the project should not be expected to lead to skill in arguing based on evidence (see Bonney et al., 2011, p. 48, for further examples).

Frameworks to Guide Outcome Development

Outcomes should be realistic, achievable, and measurable. Two evaluation frameworks developed through research and practice in informal science learning (Friedman, 2008; NRC, 2009) provide guidance in developing outcomes that meet these criteria. Each framework provides an organized way of thinking about the desired outcomes of an experience.

BOX 5-2
Definitions of Inputs, Outputs, and Outcomes

Inputs: the initial resources of the project, such as chemists, communication venues, and volunteers, but not activities, which are the various components of the communication experience.

Outputs: the direct products or services of the experience, which are typically easy to quantify; for example, the number of training workshops that staff deliver, the number of people that participate in a project, or the number of web pages that a project produces.

Outcomes: the changes to individuals, groups, or communities as a result of project participation, often described as short term, occurring within a few years of the event; midterm, occurring 4 to 7 years after the event; or long term, occurring many years after the event has commenced.

As noted previously, the 2009 National Research Council (NRC) report *Learning Science in Informal Environments* details the first framework, six interrelated strands of science learning that can "serve as a conceptual tool" for both designing and evaluating informal learning experiences. The strands encompass learning processes and outcomes and can be used for any type of evaluation—front end, formative, or summative. The report presented the set of strands as an ideal that informal learners might achieve through lifelong participation in multiple events. Most chemistry communication events cannot advance all of the strands. Communication events vary in duration and participation. Participants vary in their knowledge and interests. These variations should be considered when selecting and evaluating desired outcomes. For example, a short-term activity, such as a talk on water chemistry in a community affected by a chemical spill, might focus on engaging town citizens in the topic (Strand 1) and fostering a sense of identity as people who use and affect science (Strand 6). Thus, evaluation should focus on Strands 1 and 6. A longer-term program, such as a selective summer chemistry camp for high school students, might focus on achieving gains in all six strands.

In the *Framework for Evaluating Impacts of Informal Science Education* (Friedman, 2008), a new evaluation framework was designed, for more systematic reporting of the impacts of NSF-funded informal science learning projects, as indicated by the summative evaluations of individual projects. Using this framework, NSF made a requirement for all proposals. The Friedman framework is well known by professional evaluators and has been used for 7 years to gather and analyze data in NSF's informal science education Online Project Monitoring System (Allen and Bonney, 2011). Designed for use in summative evaluation, the framework organizes the outcomes of informal science learning into categories that roughly parallel the six strands of science learning in the NRC's 2009 report (as shown in Table 5-1).

TABLE 5-1 Participant Outcomes as Goals of Chemistry Communication Experiences

Six Strands of Science Learning (NRC, 2009)	*Framework for Evaluating Impacts of Informal Science Education Projects* (Friedman, 2008)
Strand 1: Develop interest in science, including a positive attitude toward or excitement about science and the predisposition to reengage in science and science learning.	• Engagement in and excitement about a topic or area.
Strand 2: Understand science.	• Positive attitude toward STEM-related topics, activities, theories, or careers.
Strand 3: Engage in scientific reasoning. This includes developing scientific skills such as asking questions, exploring, and experimenting.	• Knowledge, awareness, or understanding that can be stated by participants in their own words.
Strand 4: Reflect on science. This involves understanding how scientific knowledge is constructed and how the learner constructs it. It is critical for an informed citizenry.	• Skills in scientific inquiry and in learning in the particular informal environment.
Strand 5: Engage in scientific practices. This includes participating in scientific activities and learning practices with others, using scientific language and tools.	• Change in participants' long-term behavior related to a STEM topic, especially in response to environmental or health-related communication experiences.
Strand 6: Think about themselves as science learners and develop identities as people who know about, use, and sometimes contribute to science.	• Other outcomes that do not fit in the above categories.

NOTE: STEM = science, technology, engineering, and mathematics.

A comparison of NRC (2009) and Friedman (2008) suggests that integrating the two frameworks would make it easier to compare, test, and aggregate the outcomes of different informal learning experiences (Allen and Bonney, 2011). However, integration presents several challenges. First, the breadth of each set of categories makes aggregation challenging. Second, the Friedman framework meets NSF's need to assess the impact of its AISL program on society as a whole, but the NRC framework places emphasis on the learning process within individuals. Third, each framework includes outcomes that are not clearly distinguished from other, closely related outcomes. Nevertheless, the elements of both frameworks can aid chemists who are considering the desired outcomes of an event.

Evaluation Questions, Indicators, and Measures

Evaluation is driven by questions (aimed at the event planners) that focus on the intended outcomes. The evaluation questions should establish both what is and what is not to be evaluated and can be used as a tool for structuring the evaluation as a whole. Each evaluation question depends on project goals, the purposes of the evaluation, the features of the project to be evaluated, and stakeholder interests. For example, if the desired outcome is an enhanced interest in chemistry, then measurement of chemistry content knowledge following the event would not be relevant to the goal (though it might be a familiar area to assess for individuals who work in a formal education environment).

To be useful, evaluation questions must be answerable. For instance, if it is not possible to contact the participants of a broadcast media presentation on chemistry, then the evaluation questions should not address participants' behavior, attitudes, or knowledge. Evaluation questions should be developed for different stages of the project and should reflect different ways that evaluation can inform each stage. A list of example evaluation questions that could be adapted to a range of specific projects is provided in Box 5-3. The evaluation questions serve multiple purposes: assisting in targeting the important outcomes of a project and helping determine if the project's design and implementation are effective.

After establishing project goals, outcomes, and clearly articulated evaluation questions, the next task is to develop *indicators*. Indicators are measured when performing the evaluation. They provide evidence related to the targeted outcomes for participants. Indicators should directly align with the outcomes and should be clear and measurable—in the same way that a good evaluation question must be answerable. For instance, if the project intends to increase participants' content knowledge, the indicator should focus on knowledge gains rather than interest or engagement (Bonney et al., 2011). In addition to formulating indicators, evaluators identify measurement tactics to gather data related to the indicators. For example, if the intended outcome of a public chemistry demonstration is to increase participants' interest and engagement in chemistry, measurement might include any or all of the following:

- counting the number of participants;[2]
- recording the length of time participants stay;
- observing participants' facial expressions and degree of attentiveness;
- logging the types of questions participants ask of the presenter;

[2] Care should be taken with this and other indicators that could result in overestimation of interest in chemistry. For example, individuals attending an activity may not have a specific interest in the chemistry being presented but rather in the overarching topic.

BOX 5-3
Example Evaluation Questions for Different Stages of Communication

Front-End Evaluation Questions (for activity and evaluation planning)

- What topics might attract or intrigue the intended participants?
- What are the intended participants' interests, concerns, and prior knowledge related to the planned topics or issues?

Formative Evaluation Questions (to reflect on the activity)

- What made it likely or possible for the participants to participate in the project? What barriers (e.g., lack of publicity, transportation to the site) were there?
- Are participants engaging in the activities as planned? What are they doing differently than expected? What could be changed in project design or implementation to increase engagement?

Summative Evaluation Questions (to assess activity outcomes)

- Did participants demonstrate increases in any of the intended outcomes of the activity, such as increases in interest or engagement, content understanding, or identifying as a science learner, related to the topic or issues addressed? Which attendees, and to what degree?
- Did participants change their attitudes or behaviors based on the communication activity? Which attendees and to what degree?
- What level or type of involvement appeared to account for any changes or increases in the intended outcomes?

- collecting participants' descriptions of why they attended, what they liked, what they learned that was new, and what they might do next or differently based on their experience; and
- identifying any unexpected activities.[3]

Many indicators will be quantifiable, and others will be qualitative—providing insight into the value, meaning, or import of a participant's communication experience.

[3] There is value in watching for emergent behaviors that may not have been anticipated when planning the activity and goals. For instance, if the goal was that participants would imagine a new product that is based on the chemistry they are experiencing, but they also debate the societal value of such a product during the activity, then this ought to be noted in the evaluation.

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

METHODOLOGY: DESIGNING AND CONDUCTING THE EVALUATION

Balancing Evaluation Approaches

Organizers of communication activities and professional evaluators have successfully used a diverse range of indicators and measurement methods to examine outputs and outcomes in informal science settings. Using a balance of evaluation approaches supports a primary goal of evaluation: to improve the effectiveness of an experience. Summative evaluations of outcomes are undoubtedly important, but they should not overshadow front-end and formative evaluations. On the continuum between front-end evaluation (to become familiar with participants' knowledge, interests, and attitudes) and summative evaluation (to measure outcomes) are myriad opportunities for formative evaluation to reconsider, massage, and fine-tune a communication effort. Premature attempts to assess a project's summative outcomes can be meaningless or, worse, can limit chances, through formative evaluation, to continue or improve a promising event.

Evaluation Design

Evaluation design is the manner in which an evaluation is structured to collect data to answer the questions about a communication event's intended outcomes. A range of evaluation designs can be employed, including *pre-post designs*, which compare participant outcomes before and after the experience; designs that use control groups to provide more causal evidence; and designs that use mixed methods. For example, a pre-post design for a public chemistry demonstration might query the participants before and after the experience to objectively ascertain whether and how the experience influenced attitudes about chemistry. The most appropriate evaluation design for a communication event is project dependent. Evaluation design is shaped by the questions about outcomes, available resources, stakeholder expectations, and the appropriateness of the evaluation to the communication event.

Evaluation Considerations for Informal Environments

Evaluation in informal environments often requires different techniques than those used in formal settings. Evaluation can be done, but different techniques are needed.

One factor that differs between the two settings is access to the participants. Participants in informal environments (other than school groups) attend the activity by choice and cannot be required to take a survey or be tested as they could in a classroom setting. For example, participants in a chemistry demonstration at a shopping mall may not want to devote time to being interviewed or responding to a questionnaire after the demonstration. Attendees at a forum might not wish to remain after the program to provide feedback. Informal event evaluators often use an incentive to increase participation in a follow-up interview, such as a discount coupon.

Broadcast or Web-based media can facilitate summative evaluation in informal environments. For example, flyers with a web link to evaluation questions can be given to participants, to encourage them to provide feedback. Web-based evaluation has logistical issues to address, such as keeping web links up to date and encouraging a response. Overall, summative evaluation of participants in informal science learning events requires planning, persistence, and sometimes luck (NRC, 2009).

Another factor to consider is the indeterminate nature of how participants might benefit from a communication event they attend voluntarily. People engage in informal science experiences for many reasons: they were brought by friends, attracted by an intriguing tagline, or looking for new knowledge, or they stumbled into it by accident. Similarly, people draw value from informal learning experiences in different ways. And, life experiences, societal contexts, and cultural values all influence a participant's retrospective assessment of the experience. The notion of a single learning-related outcome that applies to all participants is complicated (Allen and Bonney, 2012; Friedman, 2008; NRC, 2009). For this reason, evaluations might include open-ended questions to seek unanticipated outcomes. For example, the evaluation of a calculus exhibit at the Science Museum of Minnesota revealed that the exhibit evoked powerful memories of mathematics from visitors' school days (Gyllenhaal, 2006). Although the exhibit designers had not established "evoking memories" as an intended outcome, the evaluators' use of loosely structured interviews and their flexible approach to analyzing the results allowed them to uncover and document this unexpected outcome.

In informal environments, it might be difficult to employ uniform evaluation approaches, such as standardized assessments, without sacrificing a participant's freedom of choice. It might be difficult to identify individual, as opposed to shared, outcomes. It is often impractical to use an experimental design in which participants are compared with a control group of similar individuals who did not participate. This makes it difficult for summative evaluations to conclusively attribute specific outcomes to specific communication experiences, but less imposing methods can still provide useful information. In addition, the relatively new field of informal science evaluation is exploring promising new methods to consider these difficulties and strengthen future evaluations (Bonney et al., 2011).

DATA COLLECTION

Data collection methods should be determined after developing the targeted outcomes, evaluation questions, indicators, and evaluation design. When planning how to collect data for each indicator, consider the following questions (Bonney et al., 2011, p. 53):

1. Who are the intended participants, and what specific information do you hope to get from them?
2. What method of data collection is best suited to obtain the needed information from these participants?
3. When will the information be collected, and by whom?

Based on the consideration of such questions, professional evaluators and researchers have successfully used various assessment methods to measure each of the six informal science learning outcomes identified by the NRC (2009). Interest and engagement in science (Strand 1) is often measured through self-reporting in interviews and questionnaires. For example, evaluators for the Fusion Science Theater in Madison, Wisconsin, gave participants a questionnaire before and after the performance, asking them to use Likert scales to indicate their interest in science and their confidence in their ability to learn science. The confidence ratings revealed that attending the performance had a large positive impact on the overall outcomes. Understanding of science knowledge (Strand 2) has been measured through analysis of participant conversations, think-aloud protocols (for example, having a visitor talk into a microphone while touring an exhibition), and postexperience measures, including self-reporting questionnaires, interviews, and focus groups.[4] Additional methods include engaging participants to demonstrate their learning by producing an artifact, such as a concept map or drawing, and email or phone interviews conducted weeks or even years after the event. Engaging in scientific reasoning (Strand 3) is typically measured as a learning process (i.e., how people learn) rather than as a content-driven process (i.e., what people learn). Researchers and evaluators have measured the learning process using audio and video recordings of participants, which are analyzed for evidence of skills, along with self-reports of skills. Reflecting on science (Strand 4) involves understanding how scientific knowledge is constructed and how the learner constructs it. Although such understanding is critical for an informed citizenry—a potential goal of chemistry communication—it is difficult to measure. Nevertheless, evaluators for *DragonflyTV*, a PBS program for children,[5] found an approach to evaluate whether watching the show changed children's appreciation for and understanding of scientific inquiry. They provided an opportunity before and after viewing an episode for children to rank the importance of aspects of inquiry (such as the importance of keeping some variables constant across trials and of recording results); the results showed notable gains after children viewed the show.

As these examples illustrate, the participants in the communication experience are the primary source of data for most evaluations. The assessment instruments used to collect data

[4] Note that pre- and posttests of science skills might result in feelings of failure and discourage future participation in science activities.

[5] See http://pbskids.org/dragonflytv [accessed February 2016] for details.

should be appropriate to the participants in terms of language, culture, age, background, and other potential barriers to communication. Direct involvement of human subjects in data collection may require clearance in advance from an institutional review board.

Evaluation data related to the indicators is collected through a variety of traditional methods, such as observations, interviews, questionnaires, and even tests. Other forms of data can be collected as well, including artifacts that participants create during their experience (e.g., drawings, constructions, photos, and videos), specialized tools such as concept maps, and behaviors, such as how people move through a museum exhibit, how long they spend engaging in an activity, or behaviors tracked using web analytics. The data should be collected in ways appropriate to the participants and the setting. As an example, with some participants, creative variations, such as having participants place sticky notes on a wall or drop balls in a bucket to represent their opinions, might generate better results than a standard survey. Appendix A provides sample questionnaires and sources for other evaluation instruments.

Aligning Data Collection with Outcomes

A logic model (see Figure 5-1) helps define the measurement and data collection strategies that are most likely to provide information related to the outcomes. Table 5-2 illustrates this alignment, presenting a range of chemistry communication events organized by outcome, scale of effort, and types of setting and activity. The table suggests measurement and data collection strategies that might provide evidence of whether, and to what extent, participants achieved the intended outcomes, and hence whether the project succeeded. Sometimes the measurement approach focuses on a countable number (e.g., people attending a presentation, questions answered correctly on an assessment), whereas sometimes it requires interpretation (e.g., facial expressions while watching a performance, comments about why a website was attractive and valuable). Note that rates of participation are generally indicative of how attractive an experience is to participants, and that one can infer levels of interest from participants "voting with their feet"—choosing to engage or not.

In evaluations, data collection instruments should be designed to ensure their validity (do they measure what they purport to measure?) and reliability (are the measurements stable and consistent?). Although most chemists who are evaluating communication efforts will not have the resources or the need to rigorously validate their instruments, it is important to be aware that data quality and conclusions are directly related to instrument quality. At a minimum, instruments should be tailored to the target outcomes of the event and pilot-tested with friends or family to ensure that they are measuring what they are intended to measure.

Professional evaluations also take steps to minimize sources of bias in the data. Individual chemists evaluating one-time communication activities will probably not have the resources to control for bias to the same degree as professional evaluators. Moreover, for many communication activities or programs, some biases might not pose problems to the extent they do in

TABLE 5-2 Possible Measurement Approaches for Different Outcomes and Types of Communication Activities

	Intended Outcomes for Participants			
	Engagement, interest, enjoyment (Strand 1)	Understanding of content (Strand 2)	Intentions toward future involvement or activity (Strand 6)	Impact on behavior and attitudes (Strands 1 and 6)
		Individual or small events		
Public presentations, demonstrations, and drop-in events	Length of time present, level of attentiveness, facial expression, questioning and other forms of participation, responses in brief surveys or interviews regarding why they participated, what they liked, etc.	Questions asked, verbal responses or hands raised in response to questions, responses on brief surveys regarding what they learned	Information seeking (e.g., taking brochures, filling out interest cards, liking a Facebook page), verbal responses, responses on brief surveys regarding what they might do differently	Follow-on interviews or surveys regarding discussions with others (e.g., dinner conversations), posts (e.g., Twitter), information seeking, signing up for programs
Websites, videos, broadcasts, and other media-based resources	Data analytics, posts and comments, responses on linked surveys or online forums regarding why they participated, what they liked, etc.	Data analytics, posts and comments, responses on linked surveys regarding what they learned	Participant information seeking, registering on sites, liking pages or posts, reposting online, responses on brief surveys regarding what they might do differently	Follow-on interviews or surveys regarding postexperience activities, reposts (e.g., Twitter), information seeking, registering for sites

Involvement with an after-school program, museum-based program, or ongoing public forum	Participant level of involvement (e.g., choosing "chem club" over "outdoor time" in an after-school setting), active participation in questioning and other scientific practices, responses in brief surveys or interviews regarding why they participate, what they like, etc.	Observations of participants engaging in questioning and other scientific practices with inquiry orientation, verbal responses to questions, responses on brief surveys at end of program regarding what they learned	Information seeking, verbal descriptions of plans or ambitions, responses on brief surveys regarding what they might do differently based on participation	Follow-on interviews or surveys regarding behaviors and attitudes specific to the communication goals, appropriate attitudinal assessments from ATIS or other sources
		Broader, systematic communication efforts		
Public programming and performances	Responses in brief surveys or interviews regarding why they participated, what they liked, etc., appropriate science interest assessments from ATIS	Content knowledge assessments such as the one used for *The Amazing Nano Brothers Juggling Show*	Participant information seeking, verbal descriptions of plans or ambitions, responses on brief surveys regarding what they might do differently based on participation	Follow-on interviews or surveys regarding behaviors and attitudes specific to the communication goals, appropriate attitudinal assessments from ATIS or other sources
Ongoing programming in after-school programs, museums, or public settings	Responses in surveys or interviews regarding why they participated, what they liked, etc., appropriate science interest assessments from ATIS	Content knowledge assessments carefully aligned with the experiences and objectives of the programming	Responses in surveys or interviews regarding choice of activities, courses, or careers, appropriate science attitudinal assessments from ATIS or other sources	Follow-on interviews or surveys regarding behaviors and attitudes specific to the communication goals, appropriate attitudinal and behavioral assessments from ATIS or other sources

NOTE: ATIS, Assessment Tools in Informal Science.
SOURCE: Michalchik, 2013.

larger-scale or professional evaluations. However, it is important to be aware of the ways that bias might be introduced, because bias can affect the results of the evaluation and any adjustments made in response to those results. Some forms of bias that are relevant to chemists and organizations conducting communication events include the following:

- The social desirability factor. Participants, like all people, will lean toward telling a friendly interlocutor what the interlocutor wants to hear. Questions can be formulated to avoid leading participants to what they perceive as the "correct" answer.
- Asking questions that only some participants can answer, depending on age, social circumstances, or other factors. For example, a younger child without experience at talking to strangers may say nothing about an entertaining presentation, yet her silence should not be construed as lack of interest or appreciation when compared with the response of an exuberant sibling who carries on about what fun she had.
- Sampling bias that is introduced when the only participants interviewed are ones who volunteer or show enthusiasm for the experience. Those who opt not to participate might have considerably different views of the experience. In a related vein, low response rates to a questionnaire sent after an activity might indicate a bias regarding the type of people likely to respond (e.g., people who loved the experience or those who disliked it to such a degree that they wished to express the reasons why).

In professional evaluations, data analysis begins with a focus on each individual data source (e.g., tabulating responses of parent surveys [one data source] and, separately, coding behaviors in field notes of observations of children [another data source]). Then, the evaluators synthesize information across data sources to answer each evaluation question. Decisions about how to analyze and synthesize data are complex; the bases for interpretation may be as well. A strong evaluation, however, justifies these decisions and makes the reasons for particular representations transparent, linking the *art* of evaluation to its science.

Evaluations of most chemistry communication events—particularly single activities conducted by individual chemists—are likely to be more straightforward. Most evaluations will have only one source of data (e.g., some kind of opinion survey, or interviews, or observations) and relatively small numbers of responses to tabulate.

Regardless of its complexity, the analysis process clarifies the evaluation's limitations and often reveals unexpected or serendipitous findings. The analysis phase is also the phase in which to address the implications of the results, deriving helpful recommendations for those involved and, in some cases, others engaged in similar efforts.

REPORTING AND USING THE EVALUATION

Writing up the evaluation is critical to ensure that the evaluation meets its intended purpose—to improve the effectiveness of the chemistry communication experience. Because evaluation findings do not directly make recommendations or decisions but instead inform them, the findings must be interpreted and reported in ways that are helpful to the project designers, the funders who require evaluation, or other stakeholders. For example, a chemist engaged in a one-time communication activity may conduct a front-end evaluation to learn more about the intended participants' interests and concerns. The information gathered should be synthesized and interpreted in a written report to guide the further design of the activity. Or, a chemist involved in an ongoing communication program may conduct a formative evaluation, and these findings should be summarized in writing to inform improvements in the program.

EXAMPLES OF CHEMISTRY COMMUNICATION EVALUATION

The communication efforts described in the following two cases illustrate how different the challenges of evaluating chemistry communication can be. Anyone new to evaluation of chemistry communication initiatives is encouraged to study examples available at informalscience.org and elsewhere. Appendix A suggests sources for additional information.

The Periodic Table of Videos

Starting with an initial 5-week project to create a short video on each of the 118 elements, the Periodic Table of Videos (PTOV) burgeoned into a highly popular YouTube channel (http://www.youtube.com/periodicvideos), hosting hundreds of professionally produced videos. The postings feature working chemists in their academic settings who share candid insights into their intellectual pursuits and professional lives. Although the raw number of hits, the positive feedback, and other indicators convinced them that their work was worthwhile, creators Brady Haran and Martyn Poliakoff, a journalist and a chemist, respectively, at the University at Nottingham, wondered publicly "how to measure the impact of chemistry on the small screen" (2011). A platform like YouTube comes with a built-in set of web analytics regarding viewership, but it also presents a distinct set of challenges for examining impact.

Haran and Poliakoff described their uncertainty regarding the quantitative analytics they derived from YouTube. While they recognized the value of the magnitude of the number of views ("a video with 425,000 views is clearly more popular than one with 7,000 views" [2011, p. 181]), they noted such issues as the following:

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

- One hundred views could represent one person watching the video repeatedly from different computers or mobile devices, whereas one view could represent a teacher showing it once to hundreds of students.
- Age and gender profiles rely on data that viewers provide, perhaps inaccurately.
- The meaning of geographical data, based on IP addresses, is unclear; for example, how should researchers interpret a temporary surge in viewing in a single country?
- Subscriber numbers indicate participants with a deeper level of interest, and comparisons with the subscriber base of another science channel, or a football club, provide a relative sense of PTOV's popularity, but what does it mean when people unsubscribe?
- How much do YouTube promotions of featured videos skew the data?
- Do high levels of "likes" mean that PTOV is "converting" viewers or merely "preaching to the choir"? Although few in number, what do "dislikes" mean?

The comments posted by viewers watching the videos revealed some of the nuances of their experiences and gave Haran and Poliakoff "more useful information about impact" (2011, p. 181). The authors attempted to interpret the comments quantitatively, asking whether an increase in the number of comments was a result of the PTOV itself or a reflection of a general trend. They also tried to create an index of the impact of videos based on the number of comments generated, which proved impractical. The authors additionally used a "word cloud" to analyze the comments, but concluded that this approach merely confirmed the obvious: viewers enjoyed the programs.

Haran and Poliakoff ultimately found it most "reliable" to read and interpret viewers' comments qualitatively. They identified and examined online interactions between viewers, a number of which occurred without participation from the program's producers. They also studied the email messages and letters sent to them that described how the PTOV affected the viewer, categorizing them into two primary groups:

- adults who for the first time were enjoying science, despite bad experiences with the subject in school when students and
- high school students finding their interest and aptitude in science "awakened" by experiencing an approach different from studying chemistry texts and solving problems.

They concluded that, absent a proper market survey, "these comments are probably the most accurate indicators of impact and they are certainly the most rewarding to all of those involved in making the videos" (Haran and Poliakoff, 2011, p. 182). They also concluded that there is a large market for well-presented chemistry, and room remaining in cyberspace for high-quality science communication, despite the difficulties of measuring impact.

The Amazing Nano Brothers Juggling Show

The Amazing Nano Brothers Juggling Show is a live theater performance that dramatizes the nanoscale world (atoms, molecules, nanoscale forces, and scanning probe microscopy) using juggling and storytelling in an entertaining manner. The Strategic Projects Group at the Museum of Science in Boston created the show and offers it as a live performance as well as in a DVD set on nanotechnology. The Goodman Research Group conducted an evaluation to examine the effectiveness of the show in increasing participant knowledge of and interest in nanoscale science, engineering, and technology (Schechter et al., 2010). The museum had previously collected comment cards from the participants that showed they enjoyed the program. The Goodman researchers focused on what the participants learned and how much they engaged with the content.

The evaluation analyzed data collected in spring 2010 from three different groups. The evaluators surveyed 131 children (ages 6 to 12) either before or after one of several performances using an age-appropriate survey. They also surveyed 223 teens and adults either before or after a show and interviewed 10 middle school teachers who saw it on a field trip with their classes. The surveys took about 5 minutes to complete, and participants were given a rub-on tattoo in appreciation. Up to half of the families attending each show participated. On the days that the surveys were administered, printed performance programs, which reinforce show content, were not handed out. Example survey items are show in Box 5-4.

The preshow survey involved approaching individual attendees and asking them to participate in a brief survey about the show. They were given the forms and pencils, which were collected just before the show started. At different shows, an invitation to participate in a postshow survey was announced during the show's finale by a cast member. The surveys were handed out to attendees at their seats and then collected at the theater exits.

Surveys received from attendees outside the target age group were excluded. Also, because few teens attended the performances and took the survey, only data from participants over 18 years of age were included in the analysis; teachers' responses in the interview provided the only data regarding 13-year-old middle schoolers who attended. Interviews with teachers were conducted as follow-up discussions on a date after the performance. They lasted 15 to 20 minutes and included questions about the teachers' perceptions of their students' knowledge and attitudes before, during, and after the performance. For example, teachers were asked: "Could you please tell me what would be the 'tagline' for your class's experience at the show?" and "Was the show especially good at getting across any particular concepts or insights that students had not been exposed to or that they had had difficulty grasping before seeing the show?"

On average, scores for children increased by 18 percent from pre- to postperformance, with significant increases in knowledge for half the content items in the survey. Adults' scores also increased notably from pre- to postshow survey, with significant increases in five of the

BOX 5-4
Example Survey Items from Evaluation of the Amazing Nano Brothers

Children's surveys included, among others, the following items:

- Which is smallest? Molecule, bacteria, cell, atom, or grain of sand?
- Is everything made of atoms?
- Do atoms stick to each other?
- Can scientists move individual atoms?

Questions on the teen and adult surveys were, naturally, more complex:

- Circle the SMALLER ONE in each pair:
  - atom or nanometer
  - atom or molecule
  - microscale or nanoscale
  - bacteria or virus
  - 10 million nanometers or a meter
  - 100 billion nanometers or a yardstick
- If the nucleus of an atom was the size of a basketball, approximately how large do you think the whole atom would be?
  - The size of a basketball hoop
  - The size of a car
  - The size of a football stadium
  - The size of a large city
  - The size of the United States
- Which of the following statements do you think are true? (Choose all that apply.)
  - Everything is made of atoms.
  - Atoms can be felt with special instruments but not seen.
  - Scientists can move groups of atoms, but not individual atoms.
  - Temperature affects the movement of individual atoms.
  - Atoms tend to stick together.
  - Gravity affects the movement of individual atoms.
  - Products using nanotechnology are already in stores.
  - Nanotechnology has been proven safe.
  - None of these are true.

content items. The Goodman researchers also found that the show was both captivating and informative for participants of all ages. Adults found the show highly educational. Teachers found that it reinforced classroom lessons and correlated well with science standards. The theatrical techniques supported learning potential by engaging participants. Sections of the show involved a combination of theatrical techniques that engrossed the participants and heightened their learning potential, and the juggling was successful for teaching children, teens, and adults about the structure, movement, and manipulation of atoms. For the teens and adults familiar with basic nanoscience concepts, the performance deepened their understanding.

SUMMARY

Evaluation can seem intimidating at first. Chemists conducting communication events should draw from this chapter as much or as little as necessary to assist in evaluating their projects. Simple evaluation techniques may be appropriate for a small-scale communication activity, but it may be preferable to collaborate with a professional evaluator or knowledgeable colleague when evaluating larger-scale, extended events. The primary purpose of evaluation is to gather and analyze participant data that will help the events (both the current event and future iterations) achieve their intended outcomes. Because evaluation is evidence based, carrying out at least some evaluation is more likely to lead to effective communication than not employing evaluation at all.

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CHAPTER SIX

Communicating Chemistry: A Design Framework and Research Agenda

Informed by the research described in the previous chapters and by a review of best practices, the committee developed a framework for the design of chemistry communication activities and identified key areas for future research. This chapter first discusses a design framework as an immediate step toward more effective chemistry communication. Second, the chapter identifies additional research needed to test the framework, address key unanswered questions about communicating chemistry, and provide evidence to guide continued improvement in chemistry communication.

A FRAMEWORK FOR COMMUNICATING CHEMISTRY

Throughout, this report has emphasized the potential of chemistry communication to reach a variety of participants, the challenges to reaching this potential, and the need for research-based guidance to improve the effectiveness of chemistry communication events. The committee examined the fundamental concepts relevant to chemistry communication from three fields of research: informal science education, science communication, and formal chemistry education. Based on its review of this research and its examination of recent successful communication experiences, the committee created a five-element framework for developing and implementing effective public communication activities for chemistry. The framework consists of the following:

Element 1: Set communication goals and outcomes appropriate to the target participants.
Element 2: Identify and familiarize yourself with your resources.
Element 3: Design the communication activity and how it will be evaluated.
Element 4: Communicate!
Element 5: Assess, reflect, and follow up.

Application of the framework will enhance the effectiveness of individual communication experiences while also providing the data needed to identify approaches that lead to effective informal chemistry experiences. This framework is designed to be simple and flexible so that it can be applied to a wide range of communication events in informal settings. It draws on the principles of informal science learning and science communication that were discussed in Chapter 4.

Element 1: Set Communication Goals and Outcomes Appropriate to the Target Participants

The first step in designing an effective chemistry communication event and in evaluating the event is to identify goals that are appropriate to the participants, the place, and the culture (NRC, 2009). As discussed in the previous chapter, because communication events are intended to affect the participants in some way, project goals are typically specified in terms of participant outcomes. Clarifying the project goals provides a focus for the communication project; without such a focus, the project may be ineffective. For example, one long-time science exhibit developer was working with colleagues to create a museum exhibit under a tight deadline. The team had hired an evaluator because it was required as a condition of funding, and the evaluator asked each team member to review a stack of images and identify those that best represented the exhibit content. Team members' choices diverged widely because they had not, at the outset of the project, discussed the exhibit's goals. The exhibit designer reflected, "Instead of 'Ready, aim, fire' it was 'Ready, fire, fire.' Unfortunately, the exhibition never really jelled—although it did open on time!" (Rachel Hellenga [Bonney et al., 2011, p. 4]).

To assist chemists and their collaborators (e.g., informal learning and science communication experts) in clarifying appropriate goals for the communication activity, the committee developed a set of guiding questions (see Box 6-1).

As described in Chapter 3, chemists engage with different types of participants in a number of different ways. Perhaps they have an opportunity to speak at a local Rotary Club meeting or to host a booth at a science festival, or perhaps they are working with a science museum to develop a series of Saturday morning science activities for kids. Perhaps they have been invited to contribute to an article for a local newspaper or to be interviewed on a radio show. Whatever the activity or program, the first question to ask is, "Who are my participants?" Considering this seemingly simple question follows the principle for designing effective chemistry communication opportunities from Chapter 4:

Use knowledge of the participants to identify clear and specific goals and target outcomes for the chemistry communication experience.

This question is at the core of effective design because it puts the participants and their needs or goals first, an approach shown to support effective science communication (Fischoff, 2013; NRC, 2009, 2014; see also Chapter 4).

As noted in previous chapters, when considering participants' needs, recognize that there

BOX 6-1
Guiding Questions to Aid in Setting Communication Goals and Outcomes Appropriate to the Target Participants

1. **Who are my participants?**
   a. Am I targeting a particular population segment or group?
   b. Do different segments have different goals?
   c. Why do I want to reach these participants?
2. **What will my participants find interesting, relevant, or engaging?**
   a. How can I find out what is relevant or of concern to them?
   b. What prior knowledge will the participants have (technical knowledge from schooling, knowledge from Google results, Wikipedia, or trusted websites)?
3. **What participant-relevant goals and outcomes do I want to achieve?**
   a. What will the participants get from the event?
   b. What can I learn from the participants?
   c. How will I know if I achieved these outcomes?

is not a single "public" that engages in informal science learning, but rather many publics (Burns et al., 2003; McCallie et al., 2009). If the chemistry communication event targets a particular group, the chemist should examine the motivations and interests of that group. If the activity seeks to engage multiple groups, consider whether these groups have similar interests.

It is also critical to consider one's own goals: Why do you wish to reach a particular group? Are your goals relevant to the interests of participants? If the goals of the chemist differ from the interests of participants, the chemist will need to either change the communication event goals or develop a method to draw participants with relevant interests. Often, participants are "constructed" by the type of communication event; that is, interested people are the ones who attend (Delborne, 2011). Strategic communication event planning may involve seeking out participants with interests relevant to the chemist's communication goals. In fact, participant-centered goals and the chemistry communicator's goals can be easier to align if the chemist is in a position to strategically select the participants.

As an example, consider the interests of these two groups attending a talk on water chemistry: members of a local science hobbyist group interested in reducing pond algae in town parks and citizens in a town recently affected by an industrial chemical spill into a waterway. Although the chemistry subject matter may be similar, the interests of the hobbyist group and the citizen group will probably differ widely.

The event designer should map out as much known information as possible to match the

BOX 6-2
Familiarize Yourself with Your Resources

1. Are there organizations I can partner with?
2. What opportunities or constraints will I have? (time, space, staff, physical setup of the space, equipment [A/V, safety, etc.])
3. Are there existing activities/programs/materials I can use or modify (virtual and/or physical)?

focus of the event with the interests and knowledge of the anticipated participants. Specific questions to ask include What will they find interesting, relevant, or engaging? How can I find out what is relevant or of concern to them? What prior knowledge will the participants have? For example, they may have technical expertise from formal education or training or may have some familiarity with the topic from Internet searches[1] or reading Wikipedia entries. Considering these questions leads to the second design principle for effective informal chemistry communication:

Use understanding of participants to make the experience engaging and positive.

Once information about the participants has been acquired, the event designer's goals can be investigated. These goals are generally framed as outcomes for participants, although they may also include longer-term societal impacts. As discussed in the previous chapter, two frameworks (Friedman, 2008; NRC, 2009) can assist in clarifying these outcomes. When specifying project outcomes, chemists will need to identify the relationships between participant group, goals, and venue. One can develop a goal first and then seek an appropriate venue, or vice versa. Whichever is identified first, the developer must have these three elements well described and in accord with each other to achieve the desired outcomes.

Element 2: Identify and Familiarize Yourself with Your Resources

Once the goals and outcomes have been identified, the developer must identify the available resources. Some questions to answer are shown in Box 6-2.

One of the best ways to access resources is to partner with others. For example, a developer may initially choose a readily available auditorium as the venue but then realize this location limits the activities that can be planned, such as chemistry demonstrations and hands-on activities. Partnering with a science center, however, might allow the developer to safely and

[1] As noted in Chapter 4, 60 percent of Americans cite the Internet as their main source of science information.

effectively implement these activities. With written events, such as magazine articles or blogs, a university or company public information office might provide support.

Benefits of Collaboration

Collaborations are invaluable for communicating chemistry in informal settings, as few individuals or organizations have all the knowledge, skills, access to participants, and other resources needed to develop successful activities. Collaboration has been characterized as

> a mutually beneficial and well-defined relationship entered into by two or more organizations to achieve common goals. The relationship includes a commitment to mutual relationships and goals; a jointly developed structure and shared responsibility; mutual authority and accountability for success; and sharing of resources and rewards. (Mattessich and Monsey, 1992, p. 42)

Collaborations—between chemists and experts in science communication, informal science learning, and chemistry education—not only support communication events but also (perhaps more importantly) build a community of practice that shares common goals and effective practices for communicating chemistry. Communities of practice, as defined by Lave and Wenger (1991), are "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly." The scale of such communities can vary; the field of informal science learning comprises multiple communities of practice that share common commitments to engaging participants, encouraging them to interact with natural and designed phenomena, providing portrayals of science, and building on learners' prior knowledge and interests (NRC, 2009, pp. 297-298).

Collaborations are especially valuable in communicating chemistry. Communicators in public information offices and staff members in informal learning settings often have little knowledge of chemistry and even less knowledge of current chemistry research. Chemistry researchers have limited knowledge about learning in informal settings. Thus, there are potential benefits for both parties. As Daniel Steinberg notes (in Crone, 2006, p. 1),

> science centers and museums, already accustomed to dealing with a variety of audiences, have staff trained in the communication of science concepts. They are well situated to assist facilities in meeting communication goals. The relationship is beneficial for both partners. The researchers gain greater visibility and reach a bigger audience, and the science museum gains effective and interesting public programming that can help boost attendance.

Collaborations not only link chemistry experts with informal learning or science communication experts but also provide venues for the informal chemistry learning event. For example, public information officers may have contacts at newspapers, magazines, or websites that are appropriate vehicles for written materials by chemists. Other vehicles include lectures, demonstrations, programs, hands-on activities, theater performances, forum discussions, exhibits, and so forth. These vehicles might already exist or might be created by the team of collaborators for a specific activity. Sometimes a vehicle results in a collaboration. For example, a university chemist might work with an informal educator from a science museum to take an activity developed by the Nanoscale Informal Science Education Network (NISE Net)[2] to an after-school program; NISE Net is an existing vehicle that links research scientists with informal learning educators.

Though tours are possible, members of the public do not usually visit scientists' research labs, so locations for informal chemistry communication are needed. Science museums and science cafés (often held in a pub or a coffee shop) are ideal settings. These spaces are supported by personnel who can provide guidance on effective ways to use the facility. Collaborating with an organization that can provide an appropriate venue reflects another design principle for effective informal chemistry learning from Chapter 4:

Use the nature of the experience to engage learners.

As described in Chapter 4, settings and program designs that encourage participants to think, play, and interact with one another, with the communicator, and with the materials and content tend to generate the excitement, wonder, and surprise that make the learning meaningful to them.

Collaborations may be created in the process of seeking a key resource: funding. Such collaborations are often developed as principal investigators address the Broader Impacts criterion in National Science Foundation (NSF) proposals. This criterion requires an evaluation of how well the proposed research advances discovery "while promoting teaching, training, and learning" and "broadening the participation of underrepresented groups" (NSF, 2016). A chemist might meet this criterion with little funding by bringing lab materials to a science museum to provide a communication experience. But, if the chemist wants to build an exhibit, commission a play, or conduct a summer science camp, additional funding will be needed and can be included in the proposal.

Another useful partner for a chemist is an evaluator with knowledge about informal education. As discussed in Chapter 5, evaluation can provide valuable feedback before or during implementation of an event or after, if the event will be repeated or if the chemist plans to do something similar in the future. Many universities have communication or education faculty with expertise in assessing the effectiveness of communication activities.

In sum, developing successful chemistry communication events benefits from collaboration that integrates the following:

[2] See http://www.nisenet.org [accessed June 12, 2015].

- scientists with knowledge of chemistry;
- experts with knowledge of science communication and informal learning;
- vehicles for communicating chemistry: materials, activities, programs;
- informal venues for communicating chemistry;
- financial resources or funding; and
- expertise in evaluating informal learning.

Six different individuals representing six organizations are not necessarily needed; it is often possible to obtain the components with a smaller number of institutions. For instance, a university researcher could bring the knowledge of chemistry, materials from the laboratory, and funding from an educational budget to a partnership with a science museum. The museum may be able to provide an informal learning expert, a location and participants, and a staff evaluator with knowledge of evaluating informal learning. Sometimes all of the components are found in a single institution, but the event may require collaboration between individuals.

Developing and Sustaining a Successful Collaboration

Although collaborating with (for example) a science center clearly offers benefits to chemists wishing to develop informal learning events, it can also pose challenges, as discussed in Chapters 2 and 4.

A guide from NISE Net offers useful information to address such challenges (Crone, 2006). Based on recent research and practice in science communication, the book provides advice on establishing and sustaining successful informal learning collaborations. It outlines strategies to create effective partnerships and presents guiding questions to help prospective partners determine if the proposed alliance is strategic. Excerpted below are some of the guide's recommendations for successful collaboration. Individuals and organizations can establish and sustain successful collaborations by doing the following (Crone, 2006, p. 10):

- "involving a cross-section of members, representing all the interests of the collaborating partners;
- learning about the other team members' jobs and their background and expertise;
- developing a collegial relationship involving mutual respect, understanding, and trust;
- defining clear roles and guidelines for making decisions;
- promoting open and frequent communication;
- being willing to compromise and remaining open-minded;
- defining attainable goals and objectives;
- encouraging a shared vision among the partners;
- ensuring that the project has sufficient funds, staff, materials, and time."

Collaborating with organizations can also provide chemists with access to professional development sessions to gain experience in communications, informal science education, interactions with media, and other such fields. Ideally, a chemist would develop the ability to effectively communicate science to nonscientists long before beginning a professional career. However, undergraduate chemistry students get limited experience in communication; typically, their communication experience focuses on presenting their research to other chemists. Although many chemistry majors do participate in communication activities, training to effectively communicate with the public is uneven at best.

Graduate students would also benefit from training in communication with nonscientists. A recent American Chemical Society report (ACS, 2012) recommends that graduate students should be able to "communicate complex topics to both technical and nontechnical audiences, and to effectively influence decisions." However, few graduate schools provide such education, and most of the current chemistry workforce graduated before any such courses were available. Therefore, most chemists would benefit from professional development to improve communication skills, such as the Chemistry Communication Leadership Institute (NRC, 2011) and other training programs described in Chapter 2.

Element 3: Design the Communication Activity and How It Will Be Evaluated

Taking the first two steps in the communication framework—establishing the goals of a communication event based on the participants' needs (or finding participants based on the event goals) and identifying resources to achieve the targeted outcomes, perhaps via a collaboration—provides a strong foundation for the third step: planning the event and its evaluation. At this stage, the chemist should consider how to engender trust and confidence among the participants and should identify the types of demonstrations or interactions that can best achieve the goals of the event. The chemist must test any demonstrations in advance, promote the event, and make practical arrangements (see Box 6-3).

Building Trust

Building trust between chemists and participants is an essential dimension of any effective communication activity and can be a communication goal unto itself. In general, public confidence in the leadership of the scientific community is high (Smith and Son, 2013). Efforts to build trust may help to overcome the potential communication barriers in chemistry (see Chapter 4) and to maintain the high confidence level Americans have in the scientific institution.

Trust has three primary dimensions: confidence, integrity, and dependability (Hon and Grunig, 1999). Public perception of a scientist's competence and warmth also contribute to trust (Fiske and Dupree, 2015). Scientists may be most trusted when they communicate about

BOX 6-3
Design the Communication Event and the Evaluation

1. **How do I relate to my participants to engender trust (cultural, social, shared life experience)?**
   a. What cultural, social, or political dangers or "triggers" do I want to avoid?
   b. How accessible is my message or messages?
2. **What kinds of activities or programs might be effective for achieving my intended goals and outcomes?**
   a. Are there specific activities or programs shown by research to be effective that I can use?
   b. What demonstrations or interactions can I develop to achieve my goals, applying research-based good practice and design principles?
3. **How can I test the activity or program in advance to see if it will engage my participants?**
   a. What method will I use to gather evidence about the impact of the test?
   b. How will I revise, based on the test's results?
   c. What method will I use to gather evidence about the impact of the final event?
4. **Have I taken care of all necessary organizational and promotional requirements?**

scientific information, as opposed to policy (NRC, 2014). But, effective science communication activities often focus on the science most relevant to the decisions people face (Fischoff, 2013), and students are attracted to chemistry when they encounter topics relevant to their lives (Glynn et al., 2007). Therefore, chemists must balance the benefits of engaging participants by focusing on their concerns—which often means focusing on policy issues—with the potential costs of eliciting political, cultural, or social "baggage" related to those policy issues.

Dr. Katherine Rowan, an expert on climate change communication, proposes that it is possible to overcome the barriers associated with difficult topics and to earn the confidence of participants by first conducting listening sessions to learn about participants' views, concerns, and values (Rowan, 2013). Information from such listening sessions, which could be conducted as part of Element 1 of this framework, can be used to design a communication event that aligns with participants' interests and needs, which will generate their trust. In addition, conducting a test of the event, as discussed subsequently, might uncover additional political, social, or cultural issues that could limit participants' engagement and learning, and could inform strategies to address those issues.

A chemist's institutional affiliations may influence how the public perceives some topics presented by the chemist (Critchley, 2008; Scheufele et al., 2009). A survey conducted in 2000 found that approximately one-third of respondents had an unfavorable view of the chemical industry, which was viewed less favorably than nine other science-related industries (NSB, 2002). Thus, building trust requires not only that chemists engage with members of the public, but also uphold research integrity and be transparent about their affiliations and motivations for communicating.

Designing Event Components

When identifying specific components of the communication event (e.g., visual aids, exhibits, game modules, demonstrations), the chemist should first consider the goals identified in Element 1. The components should be designed to advance the goals. If the goals include learning chemistry concepts, the chemist must consider the participants' prior knowledge and any potential barriers to learning. As discussed in Chapter 4, the abstract nature of molecular interactions, difficulty with the relationship between submicroscopic structures and macroscopic effects, and a lack of fluency with the tools of representation and symbolism in the field can be obstacles to understanding chemistry's real-world applications. At the same time, the research discussed in that chapter has identified several strategies for informal chemistry learning that could contribute to the design of components: The use of multiple linked representations to communicate a single concept is likely to help informal learners grasp it. Analogies and visual representations, such as animations and simulations, help novices understand abstract ideas and phenomena that cannot be directly observed.

The collaborations formed in Element 2 might facilitate the design of a component by bringing knowledge to the project. Science communication and informal science learning experts can facilitate the design of the overall communication event and of individual components and can sometimes identify specific components. For example, experts in informal science learning or science communication might know of a hands-on chemistry experiment that has been shown, by research or evaluation, to be effective (i.e., to advance one or more of the targeted goals for individuals who are similar to the planned participants); the chemist could simply adopt the experiment or could modify it to increase its alignment with the upcoming event's goals, participants, and venue. In addition, partnering with informal science educators and science communication experts will help ensure that the overall event design follows the research-based principles identified in Chapter 4.

Testing the Event

Testing a prototype of the chemistry communication experience helps to ensure that it will meet the needs and interests of participants. Crone (2006, p. 15) argues that "[t]o be truly visitor-centered, the development process for museum exhibits and programs must be iterative, with cycles of prototyping and evaluation." Developers of informal science exhibits have found that watching visitors use and react to a working prototype of a particular component helps them gauge visitors' enjoyment and interest, test the physical and ergonomic aspects of the component, and adjust any signage or other text to ensure that directions or information is appropriate for the participants (Crone, 2006). Other methods to measure participants' reactions to a prototype include focus groups, written surveys, and monitoring how much time they spend with individual components of an overall experience.

To plan for testing (formative evaluation) and evaluation of the final event (summative evaluation), the chemist should reflect on the questions presented in Box 6-3 and develop an evaluation plan, as discussed in the previous chapter.

Practical Arrangements

Designing and implementing effective chemistry communication experiences is a complex process involving the characteristics and interests of the participants, the event goals, the location, the duration of the event, and other factors. The chemist should attend to these practical matters. For example, because participation in informal events is often voluntary, it is important to promote the event to potential participants. Publicity via communication channels that are used and trusted by the potential participants (e.g., a hometown newspaper, a museum website) will probably attract more participants than publicity using other communication channels (e.g., an advertisement in a national newspaper).

Element 4: Communicate!

With a plan in place, resources identified, goals clearly stated, and needs of the participants identified, it's time for the experience! During the activity or program, the chemist should keep in mind the plan for the event and should note participant reactions. Additional resources can be suggested to participants. This is shown in Box 6-4.

The chemist should maintain an awareness of whether the plan is working and adjust as needed to achieve the desired outcomes. Because engagement and interest are desired outcomes at all communication events, the chemist should observe whether participants

BOX 6-4
Communicate!

1. **Am I following my plan?**
2. **Do the participants appear engaged?**
   a. Do I need to make any midevent corrections?
   b. Can I suggest resources for the participants to further engage on the topic or with the concepts, including possible Internet resources?

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

appear engaged and take action if needed. For example, if a chemist conducting a demonstration notices that some participants appear bored, he or she might stop to ask those participants questions or invite them to come forward and assist. The chemist should also consider whether the plan to engender trust (part of Element 3 of this framework, described previously) is succeeding. If not, the chemist may need to interact differently with participants to increase the focus on their needs, values, and concerns.

To supplement such informal "gut checks," the chemist, possibly with the help of a professional evaluator, should carry out the evaluation plan during the communication experience. As noted earlier in this chapter, evaluation can best enhance the effectiveness of an experience when it is integrated into all phases of design, development, and implementation. During the communication event itself, the chemist (and possibly the evaluator) should use both formative and summative evaluation to gather systematic information about participant outcomes (see previous chapter for further discussion). For ongoing communication experiences, findings from the formative evaluation can be used to make corrections. For one-time activities, findings from the summative evaluation can guide the design of similar experiences in the future.

Although participants may become engaged and interested in chemistry topics through an experience, they will need time and repeated exposure to gain conceptual understanding or scientific skills related to the topics (NRC, 2009). Recognizing this, the chemist should suggest resources to the participants for further reading, engagement, and learning, including Internet sites with accurate, relevant information.

Element 5: Assess, Reflect, and Follow Up

As discussed, summative evaluation to determine whether desired outcomes were achieved provides critical information that can be used to modify future, similar events or iterations. Reflecting on the results and modifying based on what is learned are part of the cyclic nature of program development.

The committee recommends that chemists follow this research-based framework when designing and implementing chemistry communication experiences. Because the framework includes evaluation integrated throughout the process of design and implementation, its widespread use will generate the data needed to more clearly identify the most effective approaches to chemistry communication experiences. However, accumulating and drawing lessons from such data can be difficult because scientists, informal educators, and professional evaluators use a wide range of assessment methods to measure participant outcomes, often tailored to a particular communication project or a particular medium (e.g., television versus print; NRC, 2009). Evaluation reports focus on outcomes and are typically written for and shared with stakeholders and not widely disseminated. Research, in contrast, examines not just what happens (i.e., outcomes) but how it happens (i.e., the cognitive and affective processes in participants' minds). Research carried out to generate knowledge is published in peer-reviewed journals as well as in other media (Bonney et al., 2011). Therefore, evaluation must be supplemented with research to guide the field of chemistry communication. Ideally, evaluators, researchers, and collaborators will work together to address the questions and issues discussed in the following section.

KEY AREAS FOR FUTURE RESEARCH

As part of its task, the committee was asked to consider options for future research to advance the understanding and effectiveness of chemistry communication. In considering the research that supported the development of the framework, a few opportunities were identified to strengthen the research base on informal and formal learning related to chemistry. The committee also noted opportunities for collaboration across organizations and institutions to support the implementation of the recommended framework.

Research on Public Perceptions and Understanding of Chemistry

More research is needed on science communication and informal science learning specific to the field of chemistry. Additional research should explore the role of communication in informal environments in advancing participant engagement, interest, learning, and other desired outcomes in chemistry. To address questions of funders and policy makers, such research should examine not only the short-term outcomes among participants in individual experiences, but also the longer-term effects on society, such as changing public perceptions and understanding of chemistry. Longitudinal studies are needed to track participant outcomes over time as they engage in multiple communication experiences, because extended time and exposure are required to develop conceptual understanding in chemistry. Individual studies should address such questions as the following:

- What is known about the perceptions and understanding of chemistry among different subgroups within the public, including underrepresented minorities?
- What techniques are most effective for enhancing participants' understanding of chemistry and chemical institutions in the context of broader social and political discussions?
- Are there specific science communication or informal learning activities that help people open up toward chemistry and help push aside preconceived notions?
- Does communicating chemistry in informal environments foster engagement, learning, career interest, or other desired outcomes among participants from underrepresented groups? Is the experience more effective if the communicator is a chemist also from an underrepresented group in chemistry?

- To what extent are instructional design principles that have been shown to enhance the effectiveness of chemistry learning in formal environments useful and relevant for designing chemistry communication experiences in informal environments?
- What are the effects of chemistry appearing in media stories? Do print and online media platforms such as newspapers, radio, television, websites, and social media affect public perceptions of chemistry differently from one another?
- What is the effect of chemists themselves, and the approaches they use to interact with publics, on perceptions of chemistry? For example, how can research on trust in science be applied to guide chemists in building relationships with participants through chemistry communication activities?

Digital Media for Chemistry Communication

The use of digital media and tools for communicating and learning about science, including chemistry, is advancing rapidly. However, research on the effectiveness of these tools for communicating science is limited. Available research focuses primarily on the role of computer simulations, animations, and other digital tools (like mobile phone apps or games) in engaging students in the classroom and does not answer questions about communicating chemistry in informal settings. The variety of new tools and of media with different capabilities and their use in different types of social or learning environments raises questions about both tools and contexts, such as the following:

- What is known about the effectiveness of digital tools for chemistry communication in informal environments?
- To what extent are findings about the use of digital tools in formal environments relevant and applicable to design of digital tools for use in informal environments?
- How does the use of educational technology to create virtual environments (where learners can make observations and connect them with the underlying principles of chemistry) affect engagement, learning, and other desired communication outcomes in informal environments?

Research on science communication in informal environments has not kept pace with the very rapid rise of digital tools, in particular online media and social media, as a means for communicating about science, including chemistry. The committee identified a lack of understanding of the use of social media in chemistry communication as a major gap in the current research evidence. Little is known about the extent of participation, or about measurement of the outcomes of participation, such as engagement in chemistry or learning of chemistry knowledge. Some specific questions needing further research include the following:

- What is known about whether, and to what extent, participants in social media discussions about chemistry develop engagement in chemistry, learning of chemistry concepts, or other desired outcomes?
- To what extent have new social media platforms changed overall approaches to science communication and informal science learning? What are the lessons for communicating chemistry in informal environments?
- Is the popularity of a website or other digital media platform used to communicate science related to desired outcomes for science communication in informal settings?
- How can public engagement in chemistry discussions via social media best be measured and promoted? For example, how does the number of hits on a podcast from the Chemical Heritage Foundation compare with the IFL Science[3] website's 40 to 70 million users who either interact directly with the IFL site or follow IFL tweets or Facebook posts from the site?

Addressing these questions will require interdisciplinary collaboration between chemists and social science experts on empirical approaches to communication. To support such collaboration, funders would need to engage scientists across multiple disciplines. For example, NSF would need to engage scientists across multiple directorates, including the Mathematical and Physical Sciences (Division of Chemistry), Education and Human Resources (Division of Research on Learning in Formal and Informal Settings), Computer and Information Science and Engineering, and Social, Behavioral, and Economic Sciences.

Chemistry Education and Research Policy Questions

Research is needed to explore how current policies guiding chemistry education and training, research work, and funding influence the extent and quality of chemistry communication activities, and how these policies might be changed to provide more support for communication activities in informal settings. Studies would explore such specific questions as the following:

- How do the current training, professional development, and working arrangements of professional chemists affect their motivation to conduct public communication activities?
- What educational or professional development opportunities are needed to help chemists develop knowledge and skills in informal science communication and learning, and what is known about their effectiveness?

[3] See http://www.iflscience.com [accessed June 12, 2015].

- Are the newly emerging public communications courses and fellowships within chemistry education and professional development successful in developing the communication skills they target?

RECOMMENDATIONS

The committee presents the following recommendations, synthesized from the evidence and analyses presented in this report:

Recommendation 1: Chemists should apply the proposed *Framework for Effective Chemistry Communication* to guide the design, implementation, and evaluation of chemistry communication experiences. In using the framework, chemists are encouraged to collaborate with experts on empirically based approaches to science communication, informal learning, and chemistry education.

Recommendation 2: Chemistry professional and industrial societies should encourage the use of the recommended framework by their members. These organizations should also facilitate or create avenues for the aggregation, synthesis, translation, and dissemination of research on the evaluation of and effective practices for communicating chemistry.

Recommendation 3: The National Science Foundation and other sponsor organizations should support research that examines the specific relationship between science communication, informal learning, and chemistry education through programs such as the Advancing Informal STEM Learning program (NSF, 2014). Such support should focus on topic areas where research is most needed to enhance the effectiveness of chemistry communication, in particular the following priority areas:

- public perceptions and understanding of chemistry;
- digital media for chemistry communication; and
- chemistry research and education policy, including professional development opportunities.

Recommendation 4: Chemists and experts in empirical approaches to science communication, informal learning, and chemistry education should collaborate to study chemistry communication in informal settings. Research collaborations should focus in particular on the priority areas listed in Recommendation 3.

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PART B

COMMUNICATING CHEMISTRY:
A FRAMEWORK FOR SHARING SCIENCE

The centrality of science to modern life bestows an obligation on the scientific community to develop different and closer links with the general population. That convergence will help evolve the compact between science and society so that it will better reflect society's current needs and values.

—Alan Leshner, 2003

Michael Faraday's 1827 lecture series on the chemical history of a candle, intended for nonscientist participants, is an early example of the desire to bring an understanding of chemistry to the general public. The 2011 observance of an International Year of Chemistry, planned to excite young people about chemistry and raise awareness of the field's vital role in many issues, is a more recent example. The aspiration to share chemistry with many publics is not new.

A growing body of evidence indicates that, increasingly, the public is engaging with science in a wide range of informal environments, which can be any setting outside of school such as community-based programs, festivals, libraries, or home. Yet undergraduate and graduate schools often do not prepare scientists for public communication.

This practical guide is intended for any chemist—any professional who works in chemistry-related activities, whether research, manufacturing, or policy—who wishes to communicate with the public. Whether the event will be a discussion on the chemistry of beer at a local bar or a hands-on experiment on cloud chemistry at a science fair, the goal of this guide is to help chemists improve their informal communications with the public.

At the heart of this guide is a framework, which was presented in the report *Effective Chemistry Communication in Informal Environments* (NASEM, 2016) and is based on the best available empirical evidence from the research literature on informal learning, science communication, and chemistry education. The framework consists of five elements, described in more detail in this guide, which can be applied broadly to any science communication event in an informal setting.

WHY COMMUNICATE?

From a chemist's perspective, chemistry is at the heart of many of society's conversations, including such topics as the safety of food and medicines, the consequences of ocean acidification, ensuring access to clean water, and the mechanisms and effects of climate change. For many reasons—a sense of responsibility for bringing the voice of science to conversations, a desire to share the joy of chemistry with others, a drive to encourage the next generation to pursue chemistry as a career, or others—some chemists endeavor to engage the public through public communication activities.

What motivates chemists?

Four leading goals of chemists emerged from a recent landscape study[1] commissioned by the Committee on Communicating Chemistry in Informal Settings at the National Academies of Sciences, Engineering, and Medicine on the motivations for chemistry communication:

- increase public appreciation and excitement for chemistry as a source of knowledge about the world,
- develop scientifically informed consumers (i.e., consumers who can use chemistry information to make decisions or solve problems),
- empower informed citizen participation in democratic processes, and
- encourage workforce development in the chemical sciences.

Other motivations identified from research on informal science learning and science communication include developing an appreciation for science as a way of knowing and building trust.

[1] The results of the landscape study are summarized in NASEM (2016) and the full landscape study report can be accessed at http://www.nas.edu/communicatingchemistry.

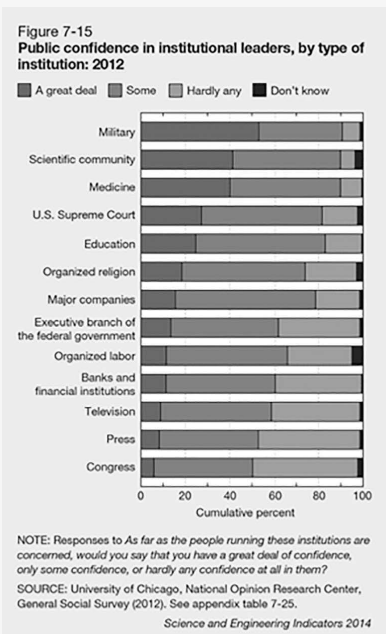
What do chemists gain?

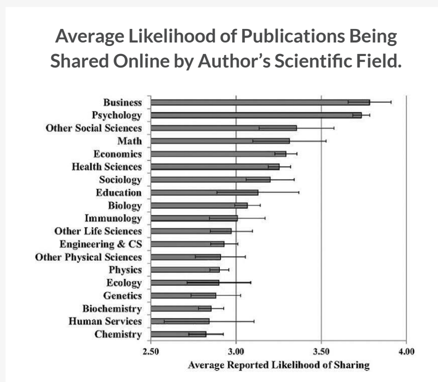
Interactions during a public communication activity may bring a chemist unexpected insights, not only into his or her own work, but also into what is important to society, for example, local concerns about a chemical's impact on water. They can also expose a lack of understanding about terms a chemist often uses to describe his or her research, or difficulties in understanding concepts. Excerpts from interviews conducted by Inverness Research Associates in 2009 illustrate what scientists gain from public communication activities:

- "Every time I've seen a scientist engaged with the public, they get a better understanding of their own research and its contact with society, and how their research actually impacts people and the environment."
- A benefit of this work is "just understanding what the concerns are of the general public, what they know, and what they don't know."

Science Is Trusted; Public Perceptions of Chemistry Needs More Study

Surveys show that the scientific community is among the top institutions in which Americans have the most confidence (left graph; NSB, 2014), and that survey respondents felt that chemicals make everyday life better (NSB, 2002). However, surveys also show that public understanding and interest is lower for chemistry than for some other scientific fields. For example, a recent survey of social media sharing habits indicated that articles written by chemists were the least shared of all the articles of the disciplines evaluated (right graph; Milkman and Berger, 2014). Public perceptions of chemistry need more study.





THE FRAMEWORK FOR EFFECTIVE CHEMISTRY COMMUNICATION

The framework for the design of chemistry communication events comprises five essential elements for developing and managing such events (see Sidebar 1). The main goal of the five elements is to reinforce a focus on participants—their interests, values, and perspectives—and to encourage awareness of and reflection on the needs and resources of both the event planner(s) and the participants.

These elements are not to be interpreted as rigid sequential steps, but rather as essential pieces that work together to iteratively refine goals and help build appropriate activities. The first three steps, in particular, must be considered together. For example, setting goals and outcomes (Element 1) will be refined as you consider available resources (Element 2) and the evaluation you plan to conduct (Element 3).

SIDEBAR 1: The Framework for Effective Chemistry Communication

Element 1: Set communication goals and outcomes appropriate to the target participants.

Element 2: Identify and familiarize yourself with your resources.

Element 3: Design the communication activity and how it will be evaluated.

Element 4: Communicate!

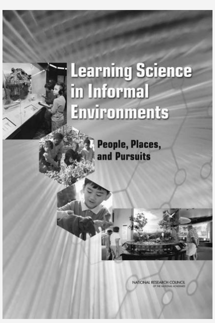
Element 5: Assess, reflect, and follow up.

WHAT DOES IT MEAN TO EVALUATE? AND WHY DO IT?

A fundamental part of the framework is the need to use evaluation as a tool to make communication activities more effective at meeting their intended goals. Too often, scientists doing informal communication do not consider evaluation. Evaluation is the only way to assess whether goals and outcomes have been met. Furthermore, *determining what will be evaluated at the outset of communication planning* will aid in the development of a communications activity that is more likely to meet the intended goals and outcomes. The evaluation process entails learning about intended participants, gathering advanced feedback about communication design, and figuring out how to determine whether the goals and outcomes have been met.

Evaluation consists of three stages, which occur during the design, implementation, or assessment of a communication activity:

1. **Front-end evaluation:** Obtain information about participants to help develop or modify goals and outcomes (Element 1)
2. **Formative evaluation:** Obtain participant responses before or during



A 2009 National Research Council report, *Learning Science in Informal Environments*, characterizes informal science learning as predominantly "learner-motivated, guided by learner interests, voluntary, personal, ongoing, contextually relevant, collaborative, nonlinear, and open-ended." Chemists should remember this when using the framework, which is intended to reinforce a focus on the participants.

an activity to assess its effectiveness before it has been fully carried out (Elements 3 and 4)

3. **Summative evaluation:** Determine if the communication activity achieved its intended goals and outcomes (Element 5)

Evaluation does not have to be complicated or costly. It has value in its simplest form and should be scaled to the scope of the communications activity. For larger-scale activities it may be important to collaborate with a third-party expert evaluator.

USING THE FRAMEWORK

Chemists might speak at a local Rotary Club meeting or host a booth at a science festival or perhaps work with a science museum to develop a series of Saturday morning science activities for kids. Other communication activities may include giving public lectures; being interviewed on a radio program; participating in hands-on learning activities in museums; writing books, articles, blogs, and Web-based materials; and using online engagement platforms to improve public access to and understanding of chemistry. Current modes of digital communication on the Internet, such as video sharing (e.g., YouTube), social networking (e.g., Facebook), and microblogging (e.g., Twitter), present new opportunities for chemists to communicate with members of the public.

Guidance on how to use each element of the framework to plan communication events is provided. An example of a chemist making a presentation at a community center is used throughout to illustrate how the framework can be used.

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

ELEMENT 1

Set communication goals and outcomes appropriate to the target participants.

Element 1 centers on two key concepts: goals and outcomes. A goal is a broad statement of what the communication activity intends to accomplish. An outcome is a specific change in an individual, group, or community as a result of participation in a communication activity. The goals of any communication activity should reflect the interests, needs, and characteristics of the participants. Chemists should use knowledge of the participants to identify clear and specific goals and target outcomes and to make the experience engaging and positive. The following are guiding questions to assist in setting participant-centered goals and outcomes:

1. **Who are my participants?**
   a. Am I targeting a particular population segment or group?
   b. Do different segments have different goals?
   c. Why do I want to reach these participants?

2. **What will my participants find interesting, relevant, or engaging?**
   a. How can I find out what is relevant or of concern to them?
   b. What prior knowledge will the participants have?

3. **What participant-relevant goals and outcomes do I want to achieve?**
   a. What will the participants get from the event?
   b. What can I learn from the participants?
   c. How will I know if I achieve these outcomes?

Who are my participants?

Information about the participants, including their level of technical knowledge and interests, is useful for developing activities that support the desired outcomes. When you begin planning, consider whether you are targeting a particular group or segment of the public. Consider characteristics such as age, technical background, and potential common interests. If the participants are children, consider possible age or developmental variations within the group. If the participants represent a broad cross-section of the public, try to determine whether they have similar goals and similar levels of knowledge on the subject matter. Participant characteristics can affect learning goals and abilities and hence can alter the appropriate communication approach. Perhaps most importantly, consider why you want to reach these participants.

As an example, you have been invited to make a presentation on the use and environmental impacts of fertilizers. The presentation will be at a local community center near a lake that has been affected by eutrophication. Will your participants be environmental activists, the local garden club, a group of local farmers, high school students, or some combination of the above? As you can imagine, each of these groups would have different perspectives and interests, as well as varying degrees of knowledge of the topic. Can you ascertain anything about their educational or professional backgrounds?

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

Such information could tell you something about their level of knowledge about chemistry. Your approach to this activity should be different for each of these groups.

What will my participants find interesting, relevant, or engaging?

Social science research clearly supports the intuitive notion that people are more engaged in an activity if it is relevant to their interests and concerns. Consider how you can find out what is relevant to your intended participants.

Continuing the example above, how can you find out who will attend your presentation on fertilizers and their impacts? How can you learn what their interests might be? A good place to start is to ask the event's organizer for participant information. Even knowing the affiliations of the registrants can be helpful. But, you may want to go further. For example, if participants are registering on a website, you could ask the organizer to add a few questions to the registration process about registrants' interest in or level of knowledge about the topic. You could also have the organizer send a survey to registrants with a reminder of the upcoming event. If there is no preregistration, on-site assessment of interests via a show of hands or applause will at least allow you to adjust your presentation in real time if needed.

What participant-relevant goals and outcomes do I want to achieve?

Communication goals may be diverse. For example, chemists may be interested in encouraging workforce development in the chemical sciences, raising awareness about a particular area of chemical

research that is relevant to major societal concerns (like the importance of chemistry in designing the next generation of antibiotics, or improving public trust in science and chemistry). Desired participant-relevant outcomes should accompany each communication goal. The outcomes you develop will not only enable you to better focus your activity, but will also provide a basis for evaluating the success of your event. Thus, outcomes should be realistic, achievable, and measurable.

After learning about the expected participants and their interests, you might set your primary goal to increase awareness of the chemistry of fertilizers and their role in the home and in agriculture. Targeted outcomes for the participants could be

- *increasing their understanding of how some fertilizers can contribute to eutrophication,*
- *increasing their awareness of available alternative fertilizers,*
- *increasing their awareness of the variety of chemistry-related research being done on fertilizers and environmental impacts,*
- *providing participants with information on how to contact the local agricultural extension office for guidance on home fertilizers, or*
- *teaching participants how to use home soil-testing kits to monitor their own soil's needs.*

ELEMENT 2

Identify and familiarize yourself with your resources.

Once the participants and goals have been identified, the next step is to identify the resources available for implementation of your event. Creating an inventory of available resources will assist in planning and in identifying gaps or opportunities. The following questions can guide you as you consider the resources you need.

Are there organizations I can partner with?

One of the best ways to access resources is to find a group or organization to partner with. Partnering with an organization such as a science center could allow a chemist to safely implement a demonstration or hands-on activity, for example. Organizations such as the American Chemical Society and the Center for Advancement of Informal Science Education may help you identify potential collaborators and opportunities to obtain funds to support the activity. Local resources—such as a Boys & Girls Club, a library, a science or children's museum, or a community group—may have opportunities to participate in an existing program or to facilitate a one-time event. Potential collaborators might also be experts in informal science education or evaluation who regularly engage in the development or assessment of informal science communication activities and also promote them.

Consider collaborating with a local nongovernmental organization experienced in communicating about the environmental impacts of fertilizers. For example, the Chesapeake Bay Foundation is a conservation organization that advocates for science-based solutions to the pollution degrading the Chesapeake Bay and its rivers and streams. The organization regularly engages in outreach activities and runs several educational programs—from field experiences for students to teacher professional development classes—to boost understanding of the Bay's poor health and of actions to improve water quality in local communities. Perhaps this organization could provide ideas for hands-on demonstrations, worksheets and online tools for participants, and also expertise in the types of participants who will likely attend and how best to work with them.

What physical resources are available, such as space, how is the space set up, and what are the safety considerations?

For activities that are in-person events (as opposed to virtual online events), the size of the event space, the number of staff, the allotted time, and monetary needs are traditional considerations that influence the type and scope of a communication activity. It is crucial to consider safety requirements for any communication activity that involves a demonstration or interactive component. Consider whether there is adequate space for participants to handle materials and whether adequate safety equipment is available. Are seats fixed in place (as is common in auditoriums) or can they be shifted to provide a buffer of safety? Will there be sufficient time to set up and to clean up after the demonstration? Consider special audience needs as well. Other considerations can include availability of a sign-language interpreter or webcasting capabilities, which would add new dimensions to an activity.

What resources will you need for your presentation on fertilizers and their impacts? One of the outcomes you developed is to teach soil testing at the event—is the space's layout appropriate for a demonstration or can it be configured to be so? Will you need help with the demonstration, such as additional staff or possibly audience members? Or, could it be a hands-on activity involving the participants? This might only be possible with a smaller number of participants and would require additional resources, such as multiple samples and testing kits. You could also consider collaborating with an environmental researcher who is an expert on the local lake and who can demonstrate eutrophication in a way that you cannot.

ELEMENT 3

Design the communication activity and how it will be evaluated.

Element 3 involves developing content for your event (in line with your goals and resources) and developing an evaluation plan that will enable mid-event modification and will ultimately determine whether you achieved your goals. Relying on intuition about which messages or engagement mechanisms will be most effective is not likely to succeed. Science communicators must understand what participants hope to gain from the experience and what they bring to it. Participants might, for example, be filling a gap in their understanding of the topic, might have misconceptions about it, or might need specific information. Use the questions in this section to brainstorm appropriate content, activities, delivery, and evaluation for your event.

How do I design an event that fully engages participants?

Many chemists rely on a presentation format to deliver information. However, event designs that encourage participants to think, play, and interact (with one another, with the science communicator, and with the materials and content) tend to generate the excitement,

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

wonder, and surprise that make the event more meaningful. Chemists can learn to effectively engage audiences from institutions that regularly engage with the public (for example, museums; see Sidebar 2).

Ensuring that content is suited to the audience is key. Analogies and visual representations, such as animations and simulations, are especially useful in helping novices understand abstract ideas and phenomena that cannot be directly observed. Also, consider having participants use the language and tools of science, for example, by choosing a problem to study, developing hypotheses about the problem, and collecting or analyzing data. Such activities foster knowledge of the scientific process, improve understanding of the relevance of science to everyday life and social issues, and develop relationships between scientists and the public.

Continuing with the content ideas you had as you considered your resources, you could decide to incorporate a hands-on soil-testing demonstration into your event. You could decide to bring soil samples from a variety of locations so that participants can compare the soil near their local lake to soil from more and less polluted areas.

How can I test the event in advance to see whether it is suitable for my participants?

A test of the communication event before the event date should be planned if possible. Testing may entail setting up a full rehearsal with test participants in the event space itself, inviting a small group of friends or colleagues to try the activity, or even just running the presentation with the event organizer. Testing will help to expose technical errors, determine whether the content (amount and level) are appropriate, get a sense of possible participant responses, and identify space constraints or resource limitations. Testing can uncover political, social, or cultural issues that could limit participants' engagement and learning, and can inform strategies to address those issues.

SIDEBAR 2:
Tips and Tricks: Learn from Museums!

Chemistry is not a topic usually featured in museum exhibits. Nonetheless, museums have a lot of experience interacting with members of the public that can help guide chemists' communication activities. To fully engage publics, one model suggests that museum exhibits should elicit the following six components (NRC, 2009, p. 83):

- **Curiosity**—the visitor is surprised and intrigued
- **Confidence**—the visitor has a sense of competence
- **Challenge**—the visitor perceives that there is something to work toward
- **Control**—the visitor has a sense of self-determination and control
- **Play**—the visitor experiences sensory enjoyment and playfulness
- **Communication**—the visitor engages in meaningful social interaction

You could rehearse your presentation with your colleagues and encourage them to think of the potential participants (environmental activists, local farmers, etc.) and ask a range of questions. You could have them practice the hands-on soil-testing demonstration to expose potential issues and ensure you have all needed parts.

What methods should I use to evaluate my activity?

How will you know if your communication activity is effective? Measurement approaches range from casual discussion, surveys, and follow-up interviews to professional assessments. Many approaches

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

are quantifiable, and others are qualitative—providing insight into the value of a participant's experience. Examples for how you could evaluate an activity are provided in Sidebar 3 and below.

For example, you decide that you might offer your fertilizer presentation again in the future, perhaps in other locales; thus, you want the evaluation to assist you in refining it. You would also like to continue your conversation with participants on the Internet. You can set up a Twitter account and plan to pass out your Twitter handle at the event or set up a blog where you will post relevant articles and accept comments and plan to pass out the website address to participants.

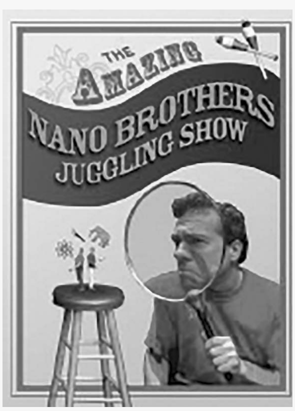


Image courtesy of Museum of Science, Boston

The Goodman Research Group conducted an evaluation of *The Amazing Nano Brothers Juggling Show*, a live theater performance (DVDs also available) that models the nanoscale world using juggling and storytelling. The evaluation was conducted through pre- and post-performance surveys (see Sidebar 3) and examined the show's effectiveness at increasing participant knowledge of and interest in nanoscale science, engineering, and technology. The results showed significant increases in learning in both children and adults and also which aspects of the show resulted in the most learning. It also found that the show was captivating for participants of all ages.

SIDEBAR 3:

Example Survey Items from Evaluation of *The Amazing Nano Brothers*

Children's surveys included the following examples:

- Which is smallest? Molecule, bacteria, cell, atom, or grain of sand?
- Is everything made of atoms?
- Do atoms stick to each other?
- Can scientists move individual atoms?

Questions on the teen and adult surveys were, naturally, more complex:

- Circle the SMALLER ONE in each pair:
  - atom or nanometer
  - atom or molecule
  - microscale or nanoscale
  - bacteria or virus
  - 10 million nanometers or a meter
  - 100 billion nanometers or a yardstick
- If the nucleus of an atom was the size of a basketball, approximately how large do you think the whole atom would be?
  - The size of a basketball hoop
  - The size of a car
  - The size of the United States
  - The size of a football stadium
  - The size of a large city
- Which of the following statements do you think are true? (Choose all that apply.)
  - Everything is made of atoms.
  - Atoms can be felt with special instruments but not seen.
  - Scientists can move groups of atoms, but not individual atoms.
  - Temperature affects the movement of individual atoms.
  - Gravity affects the movement of individual atoms.
  - Products using nanotechnology are already in stores.
  - Nanotechnology has been proven safe.
  - Atoms tend to stick together.
  - None of these are true.

There are several ways you could evaluate the activity. You could simply conduct exit surveys or (if you have staff resources) exit interviews. You could pass out preprinted, self-addressed, stamped postcards with simple questions like "Did you like this event? Circle: Yes, Sort-of, No" and "What else would you like to have heard about?" Because you will have a Web presence, you could post a survey online and direct participants to it. You could ask for feedback during your continued conversation with participants. Or, if you intend to turn this activity into a professional endeavor, you might partner with a professional evaluator.

Have I planned for the necessary organizational and promotional requirements?

If you are the event organizer, you must publicize the event. Use the participant information you gathered (see Element 1) to consider how to properly advertise the event, both to get the word out and to attract the desired participants. If analysis of the participants' backgrounds identified common interests, ask relevant groups (such as neighborhood email groups, Facebook groups, or hobbyist organizations) to aid in spreading the word. Other options are announcing the event through partner organizations and posting alerts on relevant social media outlets. Advertise through platforms that the target participants access regularly, whether in virtual or physical spaces, to increase the visibility of the event. Do not assume that participants will find out about the event on their own.

For your fertilizer presentation, you could begin outreach efforts with a search for local groups that are active in local environmental issues or that

regularly use the lake, and for individuals who are interested in agriculture (such as farmers and gardeners). Think about your topic broadly: perhaps visitors to a local zoo would be interested in the potential effects of fertilizer on wildlife, or perhaps visitors to a local science museum would be interested in the science of eutrophication. Invite the faculty and students of local high schools and community colleges to attend; also consider elementary and middle school audiences and parent groups. Contact local news outlets and add your event to community calendars. Do not leave outreach until the last minute; make it easy for participants to plan ahead to attend your presentation by promoting the event early.

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

ELEMENT 4

Communicate!

The planning is done, the announcements are out, and the day has arrived. Now what? It is time to communicate. Unless you are sure that the audience has a technical background, avoid technical details like chemical structures, formulas, and technical names or use them sparingly and define them clearly. During the event, remember your evaluation plans (see the introduction and Element 3), and monitor participant reactions to make mid-event adjustments as needed. Are the participants engaged? What seems to be of particular interest? Does it make sense to focus on one topic to maintain that interest? Is the event still working toward the intended goals and outcomes? Look for additional opportunities to continue engagement after the event, such as collecting the e-mail addresses of participants who request additional information.

How do I relate to my participants to build trust?

Building trust with participants is essential for effective communication and can be a communication goal unto itself. Trust refers to people's confidence in and willingness to open themselves up to one another. Research suggests that public perceptions of a scientist's competence, integrity, warmth, transparency, and dependability all contribute to trust. To develop trust with the participants, you might identify and discuss shared cultural or social traits. For example, impart a life experience that illustrates your connection with chemistry (why it matters to you) and your connection with the participants (why they matter to you).

You may not be trusted if you express strong opinions or take sides on a controversial or emotional topic, or if you work for an industry that has been accused of creating a problem, such as contributing to environmental degradation. If participants express concern (and even if they do not), do not be defensive; participants have a right to be concerned about issues. You should hear what they say, be open about why you believe your work is important, and share your own concerns.

Be aware of difficult cultural, political, or social issues

Difficult cultural, political, or social issues may distance you from participants. Perform a quick Internet search, including social media platforms, to see current discussions on topics related to your event. If you have time and resources, conduct listening sessions to learn about participant views, concerns, and values before the event. (These could be conducted as part of the participant information gathering in Element 1.) Also be aware that your professional and personal affiliations can influence a participant's perception of you. Transparency about your affiliations and your motivations for communicating are important for building trust.

The issue of trust is likely to be important with a topic like fertilizer use and environmental impacts. You know you might have participants with strong feelings about the use of fertilizer—for example, organic gardeners, environmental activists, or farmers who need to economize to make a living—as well as different perspectives. Some will probably be listening for any indication that you have personal, financial, or political motives for making the presentation. If you conducted a test of your presentation (see Element 3), it may have uncovered potential issues that you are now encountering.

EFFECTIVE CHEMISTRY COMMUNICATION IN INFORMAL ENVIRONMENTS

Tips and Tricks: Online Tools for Two-Way Communication

The Internet has become the primary source for science-related information, with 60 percent of the U.S. public citing it as their main source. Popular tools that enable ongoing, two-way communication include the following:

- Reddit is a popular moderated online forum in which a chemist can participate in an Ask Me Anything: scheduled forum time to answer questions and interact with people interested in science; see https://www.reddit.com/r/science for more information
- Twitter discussions such as #scistuchat, which is a themed, informal online discussion that occurs once per month created by a high school science teacher so that students can interact with scientists outside of school; see http://www.scistuchat.com for more information
- ResearchBlogging.org is a website where scientists can post information about peer-reviewed work for discussion with both peers and members of the public

You could begin building trust by disclosing up front your affiliations and motivations for speaking. Ask to hear participant concerns before you begin, and acknowledge that the concerns are legitimate (even if the science behind them may not be). If the conversation becomes challenging, stay calm, listen, and try to get the event back on track. Repeat the concerns of the participants to show that you have heard them, and reinforce the idea of the event as a learning opportunity, not a forum to debate hot issues. You could reconsider information you were planning to present, to avoid additional confrontations.

ELEMENT 5

Assess, reflect, and follow up.

The framework for public communication in chemistry is an iterative process. Plan time to assess, reflect on, and follow up on your event to improve your ability to develop future events that will be effective and meaningful for you and for participants. You might ask these questions: (1) Have I achieved my intended goals and outcomes? (2) How can I apply what I learned during my communication experience to the next time?

Your presentation on fertilizer use and impacts is over. You could ask yourself these questions: Did the evaluation sufficiently determine whether you achieved your goal of increasing awareness of the chemistry of fertilizers and their role in the home and agriculture? What happened during the presentation that might inform how it was received or how you might refine it going forward? For example, did participants ask questions that indicated they understood the chemical concepts? How did the demonstration go? Will you modify or eliminate it in the future? Do you have any indications of whether you were viewed as a trusted, neutral source of information? And finally, what did you gain from the event?

CONCLUDING COMMENTS

This guide is intended not only to aid chemists and others engaged in communicating science to the public, but also to encourage engagement with the public. The example of the chemist making a presentation at the community center is designed to illustrate both the flexibility of the framework and the scalability of its steps according to the goals of the chemist conducting the activity and the activity itself. Sidebar 4 provides a second example for how the framework could be used. It is hoped that using this guide will be an enriching experience that will better equip chemists for what is fast becoming a very important aspect of being a scientist in today's world.

SIDEBAR 4:

Using the Framework for Written Communication

If you are thinking of writing an article or a blog post, the same five elements apply.

Element 1: Are you trying to provide information? Stimulate discussion? Respond to some other article/website/tweet? Who are your intended readers? Do you know who reads the magazine/website you are posting on (based, perhaps, on looking at comments on earlier articles)?

Element 2: Do you have an editor to help you with the writing? Do you have a public affairs office that can help you reach your target audience? Will you have time to monitor responses on Twitter or on comment threads on the website? Can a student or a colleague help you do so?

Element 3: How will you decide if the article is effective: Responses from readers? "Likes" on the article's webpage? Retweets? Messages sent to an e-mail address that you provided in the article?

Element 4: Write the article and share it!

Element 5: Look at the items you identified in Element 3. How do the responses help you plan your next article?

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APPENDIXES

A
Data Collection Instruments

Most chemists or chemistry organizations doing communication events will need to borrow, adapt, or develop data collection instruments that best measure the intended outcomes of the communication. Two resources of instruments to support data collection in informal science communication are the following:

- Assessment Tools in Informal Science (ATIS), a collection of researcher development instruments for measuring many types of science outcomes, available at http://www.pearweb.org/atis
- Nanoscale Informal Science Education Network (NISE Net) Team-Based Inquiry Guide, a do-it-yourself approach to evaluating public science programs, developed for nanotechnology but broadly applicable, available at http://www.nisenet.org/catalog/tools_guides/team-based_inquiry_guide

The ATIS collection includes science assessment instruments from a diverse array of sources, organized according to age range, question format, and domain (i.e., Competence and Reasoning, Engagement/Interest, Attitude/Behavior, Content/Knowledge, Career Knowledge/Acquisition). The collection includes the Chemistry Attitude and Experience Questionnaire (CAEQ; http://pearweb.org/atis/tools/35), which is designed for first-year college students but includes some items that are potentially adaptable for other ages and settings. An example is the following scales:

Please indicate what you think about the following:

Chemists						
unfit	_	_	_	_	_	athletic
socially unaware	_	_	_	_	_	socially aware
Chemistry research						
harms people	_	_	_	_	_	helps people
creates problems	_	_	_	_	_	solves problems

Resources available from the NISE Net Team-Based Inquiry Guide website include instruments appropriate for a one-time museum visit or public event: a feedback survey, an observation form, a participant interview protocol, a question planning sheet, and a data reflection "cheat sheet." The feedback survey, for example, includes the following instructions and items:

Help us improve the program you just saw!
Please take a few minutes to share your opinions below.

1. What did you like most about this activity? Why is that?
2. What are some ways this activity could be improved? Why is that?
3. In your own words, what would you say this activity is about?

The following questionnaire provides another example of a simple instrument for gathering feedback from participants. It was developed by the Royal Academy of Engineering (UK) for projects funded by the Ingenious grant program.

Activity questionnaire – public audiences

Please take a few moments to tell us what you thought of this activity. Your comments will help us plan future activities.

These questions are about the activity
Please tick the relevant box:

Overall, the activity was . . .	**Very**	**Quite**	**A little**	**Not at all**
Enjoyable	☐	☐	☐	☐
Interesting	☐	☐	☐	☐
Informative	☐	☐	☐	☐
Interactive	☐	☐	☐	☐
Well-organized	☐	☐	☐	☐

Please ***comment*** on the activity here:

These questions are about the activity's *impact* on you

Please tick the box that describes whether you agree or disagree with each statement.

For me, the impact of the activity was…	**Agree**	**Neither**	**Disagree**
Increased awareness of the nature of engineering	☐	☐	☐
Increased awareness of the impact of engineering on society	☐	☐	☐
I'm now more interested in engineering	☐	☐	☐

Please ***comment*** on these or any other impacts here:

These questions are about you

What is your gender? Male ☐ Female ☐

What is your age? Under 16 (please state)……………………………………

16-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ over 65

Many other examples of instrumentation used by individual science communication projects, including chemistry projects, can be found at informalscience.org and at various project websites. Many communication providers adapt or develop tools to best match their own project goals and implementation features. For example, for a formative evaluation of Penn State's Marcellus Matters: EASE (Engaging Adults in Science and Energy) project, the evaluation team prompted participants with a set of "reaction words" to solicit opinions about the eight weekly sessions, which were on various topics pertinent to shale gas drilling and related science concepts and community issues. These "reaction words" prompted participants to address, for each session, what they found notably important, confusing, unnecessary, interesting, boring, relevant, familiar, unfamiliar, oversimplified, and valuable.

B
Committee Member Biographies

CO-CHAIRS

Mark A. Ratner, NAS, Northwestern University

Mark A. Ratner describes himself as a theoretical materials chemist. Arguably the youngest of the chemical sciences, materials chemistry is concerned with how chemical interactions control and determine the properties of materials. Throughout his career, Ratner has aimed to develop models to define a theoretical language for how the molecular structures of a material are manifested in its physical properties. His work has focused on several areas, including charge transport, ion transfer, nonlinear optical behavior, and quantum dynamics. Electron-transfer reactions, so fundamental to life, underlie biological processes such as photosynthesis, cytochrome p450 reactions, and cellular respiration as well as materials processes such as electrochemistry and corrosion. "It's one of the most important reactions in chemistry, which is why I've spent 30 years on it and will spend the rest of my life on it," he said. Born in Cleveland in 1942, Ratner graduated from Harvard University (Cambridge, MA) in 1964 with an undergraduate degree in chemistry. He obtained his PhD in chemistry from Northwestern University (Evanston, IL), did postdoctoral work in Aarhus and Munich, and taught chemistry at New York University (New York, NY) from 1970 until 1974. Later he served as a visiting professor with the National Sciences Research Council at Odense University (Odense, Denmark). Currently, Ratner is the co-director of the Initiative for Sustainability and Energy and is the Lawrence B. Dumas Distinguished University Professor at Northwestern University, where he served as chair of the chemistry department on two separate occasions, 1988-1991 and 2009-2012. Ratner also served as associate dean of the College of Arts and Sciences from 1980 until 1984. He was nominated to the National Academy of Sciences in 2002. Ratner has also received two honorary ScDs, from Hebrew University in 2005 and the University of Copenhagen in 2010.

David A. Ucko, President, Museums+*more* LLC

David A. Ucko shares his experience advancing informal science learning as president of Museums+*more* LLC. He also serves as vice president on the Visitor Studies Association board. At the National Science Foundation, he was section head for Informal Science Education and then deputy director and acting division director for the Division of Research on Learning in Formal and Informal Settings in the Senior Executive Service. There, he initiated the National Research Council (NRC) *Learning Science in Informal Environments* study, the Center for Advancement of Informal Science Education, the Nanoscale Informal Science Education Network, and the *Framework for Evaluating Informal Science Education Projects*. As founding president of Science City at Union Station, Ucko led the development of a themed, immersive science center as a linchpin for the $250+ million transformation of Kansas City's historic landmark. As vice president for Chicago's Museum of Science and Industry and deputy director for the California Museum of Science and Industry, he produced major exhibitions such as "Everyday Chemistry," "Technology: Chance or Choice?," and "My Daughter, the Scientist." Ucko was a presidential appointee confirmed by the Senate to the National Museum Services Board and chaired the Advocacy and Publications Committees of the Association of Science-Technology Centers. He authored two college chemistry textbooks while on the faculty of Antioch College and the City University of New York. Ucko is a Fellow of the American Association for the Advancement of Science (AAAS) and a Woodrow Wilson Fellow. He received a BA in chemistry from Columbia and a PhD in inorganic chemistry from the Massachusetts Institute of Technology (MIT).

MEMBERS

Lawrence Bell, Museum of Science, Boston
Larry Bell has worked in the Education and Exhibit Departments at the Museum of Science in Boston since 1971, where he has served as Education Associate, Director of Exhibit Research and Planning, Head of Exhibits, Associate Director, Vice President for Exhibits, and Sr. Vice President for Research, Development and Production. He was instrumental in the formation of the Science Museum Exhibit Collaborative, a collaboration of eight science centers nationwide. Through a series of National Science Foundation (NSF) grants from 1986 to the present, he developed a new model for science center exhibits, employing constructivist learning experiences to provide visitors with practice in scientific thinking skills. Currently he is engaged in the early stages of a strategic plan for informal technology education at the Museum and heads the Nanoscale Informal Science Education Network, a major NSF initiative to raise public awareness of, understanding of, and engagement with nanoscale science, engineering, and technology. He received a BS in physics and an MS in earth and planetary science from MIT in 1971.

Diane Bunce, The Catholic University of America
Diane Bunce received a BS in chemistry from LeMoyne College in Syracuse, NY, a master's in science teaching from Cornell University, and a PhD in chemical education from the Uni-

versity of Maryland, College Park, MD. She is a full professor of chemistry and the Patrick O'Brien Chemistry Scholar at The Catholic University of America in Washington, DC, where she has taught since 1985. Bunce has served as the founding feature editor and then as the associate editor for chemical education research for the *Journal of Chemical Education* since 1996. She has published articles on how students learn chemistry and the mismatch between how we teach chemistry and how the brain operates. The books she has edited on chemical education research include *The Nuts and Bolts of Chemical Education Research* and *Investigating Classroom Myths through Research on Teaching and Learning*, both published by the American Chemical Society (ACS). Bunce has also served as one of the original authors of the ACS's high school chemistry textbook (*ChemCom*) and undergraduate nonscience majors' textbook (*Chemistry in Context*). Bunce is the recipient of the ACS 2012 Pimentel Award for Chemical Education.

Julia Y. Chan, University of Texas at Dallas
Julia Chan is a professor of chemistry at the University of Texas at Dallas. Her research focuses on the single-crystal growth of novel intermetallics and oxides. Her research interests involve the synthesis of materials that exhibit metal-to-insulator transitions, mixed valence, highly correlated electronic systems, superconductivity, and materials for energy conversion. Chan's awards include the NSF Career Award, the American Crystallographic Association Margaret C. Etter Early Career Award, the Baylor University Outstanding Alumni Award, an Alfred P. Sloan Research Fellowship, the Iota Sigma Pi Agnes Fay Morgan Award, and the ACS ExxonMobil Faculty Fellowship in Solid State Chemistry. She was 1 of 12 scholars profiled in a 2002 *C&E News* series on "Women in Chemistry," which highlighted women making an impact in the chemical sciences. She is currently an associate editor of *Science Advances* and serving on the Editorial Board for *Chemistry of Materials*. Chan earned her BS in chemistry from Baylor University and her PhD from the University of California, Davis. After her PhD, she spent 2 years as an NRC Postdoctoral Associate at the National Institute of Standards and Technology.

Luis Echegoyen, University of Texas at El Paso
Luis Echegoyen has been the Robert A. Welch Chair Professor of Chemistry at the University of Texas at El Paso since August 2010. He was the director of the Chemistry Division at NSF from August 2006 until August 2010, where he was instrumental in establishing new funding programs and research centers. He was also a professor of chemistry at Clemson University in South Carolina, where he maintained a very active research program with interests in fullerene electrochemistry, monolayer films, supramolecular chemistry, and spectroscopy; endohedral fullerene chemistry and electrochemistry; and carbon nano-onion synthesis, derivatization, and fractionation. He served as chair for the Department of Chemistry at Clemson from 2002 until his NSF appointment. Echegoyen has published around 300

research articles and more than 40 book chapters. He was elected Fellow of AAAS in 2003 and has been the recipient of many awards, including the 1996 Florida ACS Award, the 1997 University of Miami Provost Award for Excellence in Research, the 2007 Herty Medal Award from the ACS Georgia Section, the 2007 Clemson University Presidential Award for Excellence in Research, and the 2007 University of Puerto Rico Distinguished Alumnus Award. He was selected as an ACS Fellow for 2011. Echegoyen is a coveted speaker who has to his record more than 300 scientific invited lectures and presentations. He was born in Havana, Cuba, in 1951. His family moved to Puerto Rico in 1960, where he spent his formative years. He received a BS in chemistry and a PhD in physical chemistry from the University of Puerto Rico, Rio Piedras. He was a postdoctoral fellow at the University of Wisconsin–Madison, and a research scientist at Union Carbide Corporation in Bound Brook, New Jersey. Realizing that his vocation was in academic research and teaching, he returned as an assistant professor to the University of Puerto Rico in 1977. Echegoyen was invited to serve as program officer in the Chemical Dynamics Program at NSF in 1981, and he held a simultaneous adjunct associate professor position at the University of Maryland, College Park. He moved to the University of Miami in 1982, where he served as associate professor and professor for 18 years. While at Miami, he took two very rewarding sabbatical leaves: one to Louis Pasteur University in Strasbourg, France, in 1990, where he collaborated with Professor Jean-Marie Lehn, 1987 Nobel Prize winner in chemistry, and a second to the ETH in Zurich, Switzerland, in 1997, where he worked with Professor Francois Diederich. Echegoyen maintains active research collaborations with researchers in Spain, Italy, France, Germany, and Switzerland and all across the United States. He has been continuously funded since the start of his academic career, and is proud to have directed the research of a very large number of undergraduate and graduate students in Puerto Rico, Miami, and Clemson, all of whom have gone on to successful academic, professional, and industrial careers.

Joseph S. Francisco, NAS, University of Nebraska–Lincoln
Joseph S. Francisco is the Dean of the College of Arts & Sciences at the University of Nebraska–Lincoln. Francisco completed his undergraduate studies in chemistry with honors at the University of Texas at Austin, and he received his PhD in chemical physics at MIT in 1983. After spending 1983-1985 as a research fellow at Cambridge University in England, he returned to MIT as a provost postdoctoral fellow. Francisco has received an NSF Presidential Young Investigator Award, an Alfred P. Sloan Fellowship, and a Camille and Henry Dreyfus Foundation Teacher-Scholar Award. In 1993, he was a recipient of a John Simon Guggenheim Fellowship, which he spent at the Jet Propulsion Laboratory at the California Institute of Technology. In 1995, he received the Percy L. Julian Award for Pure and Applied Research, the highest research award of the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers. He was selected to be a Sigma Xi National Lecturer from 1995 to 1997. In 2007, Purdue University presented to Francisco the McCoy Award—

the highest research award given to a faculty member for significant research contributions. He is a fellow of the American Physical Society and of AAAS, and in 2010 he was elected to the American Academy of Arts and Sciences. The German government selected Francisco for an Alexander von Humboldt US Senior Scientist Award, and the University of Bologna, Italy, appointed him a senior visiting fellow at the Institute of Advanced Studies. He is professeur invité at the Université Paris-Est, France; a visiting professor at Uppsala Universitet, Sweden; and an honorary life member of the Israel Chemical Society. He has been a member of the Naval Research Advisory Committee for the Department of the Navy (appointed by the Secretary of the Navy, 1994-1996). Francisco was appointed atmospheric and ocean science editor for *Pure and Applied Geophysics* from 1998 to 2001. He has also served as a member of the Editorial Advisory Boards of *Spectrochimica Acta Part A*, *Journal of Molecular Structure: Theochem*, and *The Journal of Physical Chemistry*. He is a co-author of the textbook *Chemical Kinetics and Dynamics*, published by Prentice-Hall and translated in Japanese. He has also published over 400 peer-reviewed publications in the fields of atmospheric chemistry, chemical kinetics, quantum chemistry, laser photochemistry, and spectroscopy. Francisco was president of the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers from 2005 to 2007 and served on its Board of Directors from 2003 to 2007. He currently serves on the board of directors for the Council for Chemical Research and on the executive board of the Council of Scientific Society Presidents and served on the board of directors for the ACS from 2009 to 2011. He was elected president of the ACS for 2010. President Barack Obama appointed Francisco a member of the President's Committee on the National Medal of Science for the term 2010-2012. Tuskegee University awarded him an honorary degree of doctor of science, honoris causa, in 2010.

Mary M. Kirchhoff, American Chemical Society
Mary Kirchhoff is director of the ACS Education Division and previously spent 3 years as assistant director of the ACS Green Chemistry Institute. She received her PhD in organic chemistry from the University of New Hampshire and joined the chemistry department at Trinity College in Washington, DC, following graduation. Kirchhoff spent 9 years at Trinity College, where she served as chair of the Division of Natural Sciences and Mathematics. She became involved with green chemistry when she received an AAAS Environmental Fellowship to work with the U.S. Environmental Protection Agency's green chemistry program. Kirchhoff is a co-author with Paul Anastas and Paul Bickart on *Designing Safer Polymers* and co-editor with Mary Ann Ryan on the ACS's *Greener Approaches to Undergraduate Chemistry Experiments*.

Bruce V. Lewenstein, Cornell University
Bruce V. Lewenstein (AB, general studies in the humanities, 1980, University of Chicago; PhD, history and sociology of science, 1987, University of Pennsylvania) is a professor of

science communication in the Departments of Communication and of Science and Technology Studies at Cornell University, Ithaca, NY. He works primarily on the history of public communication of science, with excursions into other areas of science communication (such as informal science education). He has also been very active in international activities that contribute to education and research on public communication of science and technology, especially in the developing world. In general, he tries to document the ways that public communication of science is fundamental to the process of producing reliable knowledge about the natural world. Among his major accomplishments, from 1998 to 2003, Lewenstein was editor of the journal *Public Understanding of Science*. He was co-chair of a U.S. National Research Council study *Learning Science in Informal Environments: People, Places, and Pursuits*, edited by Philip Bell, Bruce Lewenstein, Andrew W. Shouse, and Michael A. Feder (2009). In 2012, he was the first presidential fellow at the Chemical Heritage Foundation (Philadelphia), where he worked on issues of public engagement. He was elected a fellow of AAAS in 2002, and in 2011 served as chair of the AAAS's section on societal implications of science and engineering. He is co-author with Sally Gregory Kohlstedt and Michael M. Sokal of *The Establishment of American Science: 150 Years of the AAAS* (New Brunswick, NJ: Rutgers University Press, 1999), editor of *When Science Meets the Public* (Washington, DC: AAAS, 1992, now available online at the AAAS website), and co-editor with David Chittenden and Graham Farmelo of *Creating Connections: Museums and the Public Understanding of Research* (Walnut Creek, CA: Altamira Press, 2004). He has been an active evaluator of informal science education projects, especially in areas of "citizen science."

Michael Stieff, University of Illinois at Chicago

Mike Stieff is an assistant professor of learning sciences and chemistry at the University of Illinois at Chicago. He received a PhD in learning sciences and an MS in chemistry from Northwestern University, where he was awarded a Spencer Dissertation Year Fellowship Award for his research on human problem solving in undergraduate organic chemistry. His research examines sex differences in organic chemistry problem solving, the interaction of spatial ability and chemistry expertise, and the development of visualization software for teaching chemistry. With a grant from NSF, Stieff and his colleagues are studying how physical models help (and hinder) students in organic chemistry. This work has led to the finding that molecular models only benefit learning when students are able to physically handle models, and that teaching methods that only display models can negatively impact student achievement. To address such limitations, Stieff is developing gesture-recognition interfaces that permit students to "handle" molecular models in virtual simulations. Stieff also directs The Connected Chemistry Curriculum project, which involves the development and evaluation of molecular visualizations for teaching in high schools. This project aims to improve the achievement of urban science students through activities that involve inquiry explorations of virtual chemical reactions. Stieff has been published in *Cognition and Instruction*, the *International Journal of Science Education*, the *Journal of Research in Science Teaching*, and other journals. He has served as an assistant professor of science education at the University of Maryland in College Park, and he has taught general chemistry at the secondary level and organic chemistry for the City Colleges of Chicago.