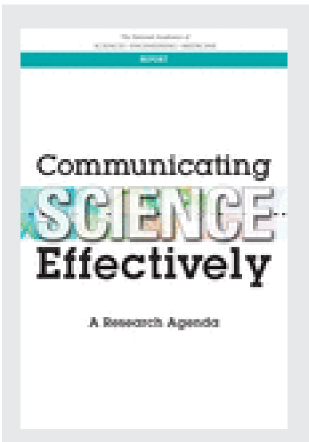

Communicating Science Effectively: A Research Agenda

DETAILS

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Communicating Science Effectively: A Research Agenda

Committee on the Science of Science Communication: A Research Agenda

Division of Behavioral and Social Sciences and Education

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The National Academies of
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COMMITTEE ON THE SCIENCE OF SCIENCE COMMUNICATION: A RESEARCH AGENDA

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Preface

Advances in science and technology have resulted in profound increases in the quality of life and health of people throughout the world, and all indicators suggest they will continue to do so long into the future. In recognition of those contributions, the public generally holds scientists and their work in high regard, and science and technology have benefited from substantial financial and other forms of public support. There are, of course, examples of cases in which the science-society relationship has experienced significant turbulence over the years—often when scientific findings conflict with religious beliefs, core human values, and long-held views or when emerging science raises ethical or political questions that science itself cannot answer. Overall, however, the relationship has been a positive one. This intimate, mutually supportive relationship between science and society places a responsibility on scientists and technologists, as citizens, to share the results of their work with the broader public so they can reap its benefits as expeditiously as possible.

Communicating about science effectively with public audiences, however, turns out to be more difficult than it might at first appear. People communicate about science for diverse reasons, there is no single audience for scientific information, and the societal contexts surrounding different scientific issues can vary considerably. Communication approaches need to be adapted to reflect the circumstances that prevail. Moreover, the complexity of scientific methods and the ways in which science progresses can also make communicating science to the public quite difficult. This challenge can be particularly acute when the issue being discussed involves either a domain in which the societal implications of the science are controversial or substantial disagreement about the findings exists within the scientific community. Fortunately, a growing body of scientific evidence can help inform the most effective ways of communicating with the public under different circumstances, and an increasing number of organizations are working to help scientists acquire the necessary communication skills. This report reviews the evidence about effective approaches to science communication and offers an agenda to help guide future research in this area. It is intended to be useful to both the practitioners of science communication and the researchers who study it.

We are extremely grateful to our colleagues on the Committee on the Science of Science Communication of the National Academies of Sciences, Engineering, and Medicine for their commitment, expertise, diligence, and wisdom in reviewing the scientific literature on science communication and their efforts in framing the research agenda presented in this report. We also benefited greatly from the dedication, expertise, and hard work of the staff of the National Academies cited in the acknowledgements that follow.

Alan I. Leshner, *Chair*
Dietram Scheufele, *Vice Chair*
Committee on the Science of Science Communication: A Research Agenda

Acknowledgments

The committee would like to acknowledge the sponsors of this study: the Burroughs Wellcome Fund, Climate Central via the Rita Allen Foundation, the Gordon and Betty Moore Foundation, the David and Lucile Packard Foundation, and the Hewlett Foundation.

Over the course of the study, the committee benefited from discussion with and presentations from several individuals who participated in its two public meetings. From the first of these meetings, held December 17-18, 2015, we thank Elizabeth Christopherson (Rita Allen Foundation); Paul Hanle (Climate Central); Chad English (Packard Foundation); Jerrold Bushberg (University of California, Davis School of Medicine); Cornelia Dean (*New York Times*; Brown University); Richard Harris (National Public Radio); Brooke Smith (COMPASS); Baruch Fischhoff (Carnegie Mellon University); Bruce Lewenstein (Cornell University); and Arthur Lupia (University of Michigan). From the second public meeting, held February 24-25, 2016, we thank Seth Mnookin (Massachusetts Institute of Technology); Noel Brewer (University of North Carolina at Chapel Hill); Ed Maibach (George Mason University); Rick Spinrad (National Oceanic and Atmospheric Administration); Bob Inglis (RepublicEn); Brian Baird (4Pir2 Communications); Daniel Sarewitz (Arizona State University); Rush Holt (American Association for the Advancement of Science); Dominique Brossard (University of Wisconsin-Madison); Noshir Contractor (Northwestern University); and Hilda Bastian (National Center for Biotechnology Information; National Institutes of Health).

The committee also applauds the staff of the National Academies of Sciences, Engineering, and Medicine—Melissa Welch Ross, Holly Rhodes, Emily Backes, and Leticia Garcilazo Green—for their dedication to the study and their important contributions to the preparation of this report.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Academies of Sciences, Engineering, and Medicine. 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 deliberative process.

We thank the following individuals for their review of this report: David B. Allison, School of Public Health Dean's Office, Office of Energetics, University of Alabama at Birmingham; David Auston, Institute for Energy Efficiency, University of California, Santa Barbara; John C. Besley, Department of Public Relations, Michigan State University; Rick E. Borchelt, Communications and Public Affairs, Office of Science, U.S. Department of Energy; Dominique Brossard, Life Sciences Communication, University of Wisconsin-Madison; James M. Druckman, Department of Political Science, Northwestern University; R Brian Haynes, Health Information Research Unit, McMaster University, Hamilton, Ontario; Bruce V. Lewenstein, Department of Communications, Cornell University; Rebekah Nagler, School of Journalism and Mass Communication, University of Minnesota; Rajiv N. Rimal, Department of Prevention and Community Health Milken Institute School of Public Health, George Washington University; Brooke Smith, Director's Office, Communication Partnership for Science and the Sea (COMPASS), Portland, Oregon; Elke U. Weber, Departments of Energy and the Environment, Psychology and Public Affairs, Princeton University.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions, nor did they see the final draft of the report before its release. The review of this report was overseen by Alan Lesgold, Learning Research and Development Center, University of Pittsburgh, and May R. Berenbaum, Department of Entomology, University of Illinois at Urbana-Champaign. Appointed by the National Research Council, 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.

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Summary

Science and technology are embedded in virtually every aspect of modern life. As a result, people face an increasing need to integrate information from science with their personal values and other considerations as they make important life decisions about vaccinating their children and other medical care, the safety of foods, what to do about climate change, and many other issues. Communicating science effectively, however, is a complex task and an acquired skill. Moreover, the approaches to communicating science that will be most effective for specific audiences and circumstances often are not obvious. Fortunately, an expanding science base from diverse disciplines can support science communicators in making these determinations.

The purpose of this report is to offer a research agenda for science communicators and researchers seeking to apply this research and fill gaps in knowledge about how to communicate effectively about science, with a particular focus on issues that are contentious in the public sphere. Examples include climate change, stem cells, nanotechnology, vaccines, hydraulic fracturing, genetically modified organisms, nuclear energy, obesity, education policy, and the teaching of evolution and climate change in K-12 schools. To inform the research agenda, the study committee sought to identify important influences—psychological, economic, political, social, cultural, and media-related—on how science associated with such issues is understood, perceived, and used. For the purposes of this report, "science communication" is defined as the exchange of information and viewpoints about science to achieve a goal or objective such as fostering greater understanding of science and scientific methods or gaining greater insight into diverse public views and concerns about the science related to a contentious issue.

CROSS-CUTTING ISSUES

Although each societal concern entails unique issues that need to be considered if science is to be communicated effectively, some issues cut across all of science communication.

Aligning Goals with the Right Communication Approach

The most effective approach for communicating science will depend on the communicator's goal. The committee identified five such goals for communicating science, each of which places quite different demands on the knowledge and skills of science communicators and their audiences and calls for its own distinct approach:

- **Simply to share the findings and excitement of science.**
- **To increase appreciation for science as a useful way of understanding and navigating the modern world.** This goal assumes that people who have more knowledge about and are more comfortable with science will be more willing and able to use knowledge from science in their everyday lives. This assumption has not yet been fully tested.

- **To increase knowledge and understanding of the science related to a specific issue.** In this case, communicators may seek to inform or educate people about the relevant facts from science and their meaning for the issue.
- **To influence people's opinions, behavior, and policy preferences.** This goal becomes salient when the weight of evidence clearly shows that some choices or policies have more positive consequences for public health, public safety, or some other societal concern.
- **To engage with diverse groups so that their perspectives about science related to important social issues can be considered in seeking solutions to societal problems that affect everyone.** Meeting this goal requires understanding the concerns of each group and working together to find acceptable solutions by, for example, identifying important research questions that scientists should be exploring further.

Given this diversity of goals, a major research effort is needed to help science communicators select approaches that best match their particular goals. It is important to emphasize, moreover, that science communication often is undertaken to achieve a larger end that goes beyond discussion of the science itself—for example, to affect health behaviors or to encourage a particular policy choice. In these cases, it is possible that means other than simply communicating the science may be more effective at accomplishing such goals. In such a context, two important questions arise: How much does science communication matter to the achievement of end goals relative to everything else that matters? and How do various ways of communicating scientific information[1] augment or alter how science is weighted or used in making decisions?

Moving Beyond the "Deficit Model" of Science Communication

A second overall issue is that the most widely held, and simplest, model of what audiences need from science communication—what is known as the "deficit model"—is wrong. A common assumption is that a lack of information or understanding of science fully explains why more people do not appear to accept scientific claims or engage in behaviors or support policies that are consistent with scientific evidence. The research on science communication, however, shows that audiences may already understand what scientists know but, for diverse reasons, do not agree or act consistently with that science. People rarely make decisions based only on scientific information; they typically also take into account their own goals and needs, knowledge and skills, and values and beliefs. A related widespread assumption in both the scientific and science communication communities is that if only science communication were done "better," people would make choices consistent with scientific evidence. This assumption has not been fully tested in diverse situations. And although people may need to have more information or to have information presented more clearly, a focus on knowledge alone often is insufficient for achieving communication goals.

[1] The term "scientific information" is used throughout this report to denote knowledge from science and how it is produced.

The Ethics of Science Communication

Choices about what scientific evidence to communicate when, how, and to whom can be a reflection of the communicator's values. This fact becomes especially salient when the science pertains to an individual decision or policy choice that is contentious. One important ethical question is how far science communicators should go beyond simply communicating scientific facts and theories in an effort to influence decisions. Individual science communicators have differing perspectives on their roles as advocates, and this issue will continue to be debated. Yet that debate, while important, is beyond the scope of this study. The focus of this report is on science communication that conveys scientific information and helps people assess how that information may apply to a particular situation. In exploring these topics, the report draws on research on other types of communication, such as public health campaigns, that may be designed to persuade people to change their behaviors but may or may not include underlying scientific information.

MAJOR CHALLENGES FOR RESEARCH AND PRACTICE IN SCIENCE COMMUNICATION

Research and practice in science communication face a number of challenges. Some of these challenges are common to all communication, but others are unique to science communication. These challenges include the converging influences on science communication; challenges of engaging formally with the public about science; the special complexities of communicating science when it is part of a public controversy (science-related controversy); and the complex, dynamic and competitive communication media environment.

Converging Influences on Science Communication

A number of factors contribute to the complexity of communicating science, regardless of whether the science is part of a public controversy. These factors relate to

- the complex nature of scientific information;
- the ways in which people process such information; and
- social influences, such as social networks, norms, group memberships, and loyalties.

Further study is needed to determine the importance of these diverse factors to communicating with specific audiences and how these factors interact in various contexts to affect the ability of science communicators to achieve specific goals.

In addition, many of the decisions to be made about societal issues occur in the realm of policy. Information about the actual impact of science communication on policy decisions, however, is sparse. Several important questions in this area need to be addressed. For example,

- How is scientific information accessed, encountered, understood, shared, or discussed by policy makers in formal policy processes?
- How can science communication affect these processes? and
- How are these policy processes affected by science communication when science is involved in public controversy?

Think tanks, scientific associations, evidence-based clearinghouses, government agencies, and nonprofit organizations all play an organized role in interpreting scientific information for use by policy makers, the media, and the broader public. Research is needed on the conditions for success—such as affecting the quality or outcomes of policy discussions—in the efforts of diverse types of organizations to communicate science.

Challenges of Engaging Formally with the Public about Science

The purpose of formal public engagement is to facilitate the exchange of information, knowledge, perspectives, and preferences among groups that differ in expertise, power, and values (National Academies of Sciences, Engineering, and Medicine, 2016) and help them find common ground. Elected officials, government agencies, and other public- and private-sector organizations often seek to engage the general public in discussions with scientists about important science-related issues. Effective public participation is difficult, although some principles for success can be gleaned from the environmental policy and assessment literatures.

As formal public engagement is undertaken on such diverse issues as gene editing, biomedical research, and health policy, important questions for research arise, such as

- What are the particular structures and processes for public engagement that best enable science to be communicated effectively? and
- To what degree do these approaches generalize or need to be tailored according to the diversity of the participants, the decisions to be made, and the nature of the topic?

The Special Complexities of Communicating Science in the Face of Controversy

The involvement of science in public controversy makes the already complex task of science communication even more so. Science-related controversies take different forms and arise for diverse reasons, and they occur in particular historical and cultural circumstances. Better understanding of the origins and dynamics of such controversies will be necessary if science communication is to be more effective. In addition, science-related controversies have three key features about which more needs to be known.

First science-related controversies typically involve conflicts over beliefs, values, and interests that are central to the debate rather than simply a need for knowledge from science. Research is needed to determine how science can be communicated effectively in these conditions.

- Additional research is needed to determine how much of an effect science communication can have in these circumstances, for whom, and in what contexts.
- Given the importance of audience perceptions about the trustworthiness and credibility of the communicator, research needs to examine the effects on audiences when science communicators are open about their own values and preferences.
- The best strategies for communicating science about contentious social issues if there is distrust of the science or of the scientific community need to be investigated.
- Commonly considered best practices in public engagement suggest the importance of engaging with those concerned with an issue early on, but research is needed to

determine to what extent and in what ways communicating science during public engagement processes can be effective once an issue has already become controversial.

- Research needs to explore the structures and processes for communicating science effectively across a range of social issues and types of science-related controversies.

Second, the public often perceives uncertainty either in the science itself or its implications or as a result of various communicators conveying different, and sometimes contradictory, messages. In some science-related controversies, uncertainty can be mischaracterized, exploited, or exaggerated to serve particular interests.

- Effective ways of communicating scientific consensus, as well as degrees or types of uncertainty, need to be identified.
- Research is needed to develop detailed approaches to understanding audiences' responses to uncertainties about science in cases of science-related controversy that can be implemented on a large scale.

Finally, in science-related controversy, the voices of organized interests and influential individuals are amplified in public discourse and can impede clear communication about the state of the scientific evidence. High stakes, conflicting interests, uncertainty, and concerns about risk and its consequences all can expand the number and diversity of people and organizations that are attempting to communicate about as well as using science. In this context, misinformation can make it difficult for authoritative voices from science to be heard.

- Research is needed to identify effective strategies for correcting misinformation and to determine the role of different communicators, such as opinion leaders, in affecting people's awareness and understanding of accurate scientific information.
- Research needs to investigate effective ways of framing or reframing an issue, how much framing matters, and when is it best done.

The Complex, Dynamic, and Competitive Communication Media Environment

Science communication today takes place in a complex and rapidly changing media environment, and new ways of communicating are constantly emerging. These changes present both opportunities and challenges for communicators of science, regardless of whether the science is involved in public controversy. The ways in which complex and evolving media affect people's engagement with scientific information is a relatively new area of research. For the future, it will be important to determine how individuals and decision-making bodies derive and evaluate information from various sources. Future research also will need to keep pace with changes in the media landscape as they occur and devise more comprehensive models for science communication. More needs to be known in particular about the following:

- How can accurate information about the state of the science be heard among many competing messages and sources of information?

- How can science communicators reach audiences that face barriers to accessing and using scientific information, such as those with lower levels of education and income or those with strongly held views?
- Are some forms of media better than others in promoting awareness or understanding or informing public opinion about scientific information or science, and if so, for whom?
- Despite the growing impact of new media, much of the scientific information that Americans receive through media originates from traditional journalism. It is important to understand and track over time how science is covered in the media to determine how the media are affecting people's perceptions, understanding, and use of science in a dynamic communication environment.
- People's social networks are known to affect their beliefs, attitudes, and behaviors, and social media and blogs also are increasingly being used to spread both accurate and inaccurate scientific information. Research is needed to determine roles and effective approaches for communicating science through social media platforms and blogs.
- Better understanding is needed of the effects of changes in media on how people understand and perceive science through social media and other social networks. The use of tools such as social network analysis could be explored to document the flow of information and sentiments in social networks and assess their effects.

GENERAL CONCEPTUAL AND METHODOLOGICAL ISSUES

Several conceptual and methodological considerations relate to all research on science communication. These include the use of a systems approach to guide the research, the need to determine which communication approaches work best under which circumstances, and the importance of building a coherent science communication research enterprise.

Use of a Systems Approach to Guide the Research

Science communication occurs in a complex context whose elements include the content to be communicated, the communicator, the audience, the channels of communication, the other diverse organizations and individuals that are also communicating science, and the many other sources from which audiences may obtain additional and perhaps conflicting or inaccurate information about science. Moreover, people's understandings and opinions about science in general and its relevance to specific issues change over time. Advances in science communication will require a robust understanding of each of these interacting elements and their dynamics both individually and collectively—what is often called a systems approach. Such an approach, which has been applied in many other fields, could help researchers and science communicators consider the interactions among the various elements involved in science communication and its context as they occur in the real world.

The Need to Determine Which Communication Approaches Work Best under Which Circumstances

Substantially more research is needed to help science communicators determine which approaches to communicating are effective for whom and under what conditions for achieving specific communication goals. Research focused in the following ways would be especially informative:

- randomized controlled field experiments to assess the impact of a particular approach to communicating science on changes in people's understanding, perception, or use of science;
- research that, to the extent possible, simulates the conditions of real-world communication environments; and
- analyses of large datasets, such as those derived from social media and other emerging online communication platforms, to assess changes in people's responses to science communication.

Efforts are needed, perhaps in the form of registries such as those that exist in the health sciences, to aggregate and share information from effectiveness studies so an evidence base can be built. These efforts could catalog evaluation studies according to key dimensions to identify factors that affect science communication and the elements of various approaches to communicating that may generalize across topics or be specific to certain circumstances. Such efforts also are needed to help researchers address the challenge of accessing and utilizing research relevant to science communication across disciplines.

The Importance of Building a Coherent Science Communication Research Enterprise

To achieve real progress in understanding what makes for effective science communication, it will be necessary to direct particular attention to four key aspects of a coherent science communication research enterprise.

First, researchers and practitioners of science communication need to form partnerships to translate what is learned through research into practice and to develop detailed research agendas for testing hypotheses about how to communicate science that are realistic and pragmatic. Researchers need to be actively engaged with the various professionals and organizations that communicate science and take into account their particular motivations for communicating and the context in which they work. Researchers and diverse science communicators need to have opportunities and mechanisms for the regular exchange and synthesis of information and ideas, and to work together to study science communication in real-life contexts, where it occurs.

Second, the diverse disciplines that study aspects of science communication and science-related controversies are similarly disconnected. Researchers in these various disciplines need opportunities and mechanisms for working together to develop more unified theories, concepts, and definitions of the factors that matter to communicating science. New or refocused journals for science communication research and professional meetings and other forums would support interdisciplinary and practice-driven research collaborations.

Third, given the complex individual and social phenomena involved, more scientists need to be recruited to this field from neighboring disciplines, particularly the social and behavioral sciences. Science communication researchers at all career levels may need additional training to carry out the research agenda proposed in this report, or may need to be encouraged to work in teams that include partners with the necessary expertise.

Fourth, having mechanisms for the rapid review and funding of certain science communication research is important. The need for such mechanisms becomes clear when such issues as the Zika virus emerge suddenly, and important messages from science need to be communicated. To this end, it would be necessary to address policies that can make timely research difficult.

A FINAL WORD

Many studies reviewed by the committee are compelling and suggest ideas for practice. It is important, however, not to overgeneralize from the research conducted to date. In many cases, studies need to be replicated and extended to provide greater certainty about their results and to determine whether they apply to diverse audiences. This work ideally would begin with in-depth, comprehensive reviews of existing research related to science communication. Just as important, research on science communication, which tends to focus on detailed questions, needs to be aggregated and integrated into a more coherent enterprise. Simple solutions are unlikely; needed instead is a nuanced understanding of how best to communicate science for the benefit of society across different settings, issues, and audiences.

The committee hopes the research agenda outlined in this report will be pursued not only by researchers in academic settings but also by those embedded in the various types of organizations that communicate science. Progress will require the collective expertise of science communicators and scientists. Two National Academy of Sciences Arthur M. Sackler Colloquia on the Science of Science Communication, as well as the convening of this committee, point to the readiness of science communicators and researchers from diverse fields to address this need and work toward science-informed approaches to science communication.

1
Using Science to Improve Science Communication

Science and technology are embedded in virtually every aspect of modern life. For this reason, people increasingly face the need to integrate information from science with their personal values and other considerations as they make important life decisions, such as those about medical care, the safety of foods, and a changing climate. The practice of science always involves some degree of uncertainty, and as a human endeavor, it is inevitably subject to occasional errors and to the potential influence of personal values, biases, and professional interests. Nonetheless, science helps explain and predict the world using a unique, rule-governed process to produce factual knowledge, and in the long run, the practices and norms of science result in a robust base of knowledge.

Many believe the scientific community has a duty to engage with society to disseminate this knowledge and provide a return on society's investment in the science enterprise (Dewey, 1927; Lubchenco, 1998). Society in general expects scientists to help solve its major problems (such as maintaining people's health or safeguarding national security) and to discover ways of improving quality of life, expanding economic opportunities, and informing decisions. Yet communicating science effectively does not come easily; it is an acquired skill.

Any communication involves a communicator, an audience, and channels of communication that are often bidirectional, all situated in a particular social context. Many envision "science communication" as a scientist giving information to another individual, such as a member of Congress or of the media, about a scientific topic. Most science communication, however, is more dynamic and takes place in a much more complex context involving individuals, groups, and organizations that are both the communicators of and audiences for science. These contextual elements pose challenges for effective science communication. So, too, does the very nature of science. The methods scientists use to understand the world are unlike the ways people typically think on a day-to-day basis. The results of science also can be insufficient, ambiguous, or uncertain, and scientific conclusions can change over time as new findings emerge. These inherent characteristics of science can create barriers to communication and understanding.

Other barriers to effective science communication may stem in part from the audience for the information. These barriers include a lack of familiarity with science in general or with the scientific findings and issues related to a particular decision. Faced with making sense of a vast amount of complex information that is often quantitative and can at times appear contradictory, some people—including scientists in areas outside their expertise—often use shortcuts (as discussed in more depth in Chapter 2). People may rely, for example, on a quick assessment of whether the information fits with what they already know and believe about the subject. Or they may decline to engage, instead relying on someone else's evaluation of the information. In many cases, people protect their personal or economic interests, beliefs, and values from information that appears to conflict with them (as discussed in detail in Chapter 3). Although scientists may feel compelled to follow what science is saying about an issue, the rest of the public may feel freer to disregard or even distort that information.

Audiences for science sometimes are blamed when science communication appears to have failed ("the public does not care"; "they were too uneducated to understand"). However, communicators themselves can introduce barriers to effective communication. For example, they may fail to identify clear and feasible goals for their communication, including what information people need to know. At the same time, communicators tend to overestimate what most people know about a subject (Nickerson, 1999), as well as to overrate the effectiveness of their efforts (Chang et al., 2010).

Navigating these and other challenges is a skill—one that many communicators have lacked opportunities to learn. Few scientists, for example, have had formal training in science communication, although a variety of programs for such training exist (e.g., the Leopold Leadership Program; see also Neeley et al., 2015) and are becoming the focus of research (Besley et al., 2016). Moreover, many journalists, institutional public information officers, advocates, and others who communicate science in the course of their work lack training either in science or in the communication of science per se (Dunwoody et al., 2009). And science must compete for attention in a complex and fast-changing media environment that can be difficult to penetrate (an issue discussed further in Chapter 4).

PURPOSE AND SCOPE OF THIS STUDY

This study was undertaken in this context to respond to the expressed needs of both those who communicate science and those who study how to communicate it; the statement of task for the study is presented in Box 1-1. This report offers a research agenda for science communication practitioners and researchers seeking to apply research related to science communication and build an evidence base useful for making decisions about how to communicate science most effectively.[1] Of particular concern to the study sponsors are gaps in knowledge about effective science communication when science related to contentious issues is involved in public controversy (science-related controversy). Prominent examples of such issues include the reality and nature of climate change, how society can meet its energy needs, the importance and safety of childhood vaccination, how to prevent obesity, and issues of food safety (such as disagreements about the risks, or lack thereof, posed by genetically modified foods or chemical additives in food and water).

For the purposes of this report, "science communication" is defined as the exchange of information and viewpoints about science to achieve a goal or objective such as fostering greater understanding of science and scientific methods or gaining greater insight into diverse public views and concerns about the science related to a contentious issue. Consistent with its charge, the committee considered the research literature from a wide range of disciplines to examine similarities and differences in the factors associated with communicating science related to contentious issues.

From this review of the salient literature, the committee identified a set of factors that make effective science communication particularly challenging; ways to deal with those challenges are the focus of the research agenda proposed in this report. A "challenge" is defined here as a major and complex barrier to effective communication that, while difficult to

[1] For a related discussion of this need, see National Academy of Sciences (2014).

overcome, could be addressed by filling current gaps in knowledge about the nature of the challenge and how it can be overcome. Taken together, the gaps in knowledge related to these challenges offer a road map to guide future research and help improve the quality and effectiveness of science communication.

BOX 1-1
Statement of Task

An ad-hoc multidisciplinary committee of experts will produce a consensus report that synthesizes what is known from research about effective science communication and describes a comprehensive research agenda to improve the communication of science related to important societal issues and decisions that are often contentious.

The committee will:

- identify the psychological, social, cultural, contextual, political, and economic factors, media influences, and communications approaches that affect how science relating to a broad range of issues (e.g., childhood vaccinations, nanotechnology, climate change, food safety, healthy behaviors), is understood, perceived and used and how change in the understanding, perception and acceptance of science occurs;
- examine similarities and differences in the influence of these factors across issues, and identify those that, if better understood, have the greatest potential to improve the communication of science on contentious issues;
- develop a conceptual framework to guide its synthesis and research recommendations with consideration of the following: communication purposes (goals and objectives); audiences and participants; communication setting, tools, devices, social interactions, and networks; type of media; type of social issue or science domain;
- identify critical issues related to research design and measurement.

Each chapter in this report focuses on

- a specific challenge or set of challenges and their importance for effective science communication;
- what is known from research about the conditions that affect peoples' understanding, perception, and use of science; and
- needs for research and innovation.

A large body of research and scholarship has examined the factors—psychological, political, societal, cultural, economic, moral, media-related, and institutional—that influence science communication. However, much of this scholarship touches on a single issue area (nuclear energy, for example, or genetically modified organisms). This report differs from most previous analyses in that it represents an attempt to distill key findings about communicating science across many issues and academic disciplines. It is intended to provide an integrated understanding of the challenges of communicating science and the factors that influence people's understanding, perception, and use of science that relates to contentious issues.

To keep its review of the relevant literature manageable, the committee focused mainly on past or current disputes involving science related to contentious issues that include climate change, stem cells, nanotechnology, vaccines, hydraulic fracturing, genetically modified organisms, nuclear energy, obesity, education policy, and the teaching of evolution and climate change in K-12 schools. These topics involve many shared elements of science-related controversy, yet also are sufficiently diverse to inform an examination of the personal, economic, political, social, and cultural influences entailed in communication, all of which science communicators need to understand.

In addition to examining studies related to the above specific contentious issues, the report draws on research in a range of related disciplines (such as health communication, environmental communication, risk communication, political science, marketing, social marketing, mass communication, and journalism) to elucidate influences on the way people encounter and make sense of science, both as individuals and as members of social groups and organizations (such as governments, advocacy groups, and religious communities). The committee also gathered information from people who may be characterized as "science communication practitioners"—professionals who communicate about science, including scientists themselves, but do not do conduct research on science communication.

The committee did not assume that findings from studies of other forms of communication would transfer automatically to communicating science. Science offers a unique way of understanding the world, and so knowledge about communication in other domains may not translate entirely to communicating science, especially when science is involved in controversy. It also cannot be assumed that the literature on decision making per se will necessarily generalize to communicating science for decision making. Another consideration is that the goals of communication studied in other disciplines may or may not be consistent with the goals of some science communicators. For example, some fields, such as marketing and public relations, offer insights into several aspects of science communication—for example, understanding audiences—but the goals of marketing and public relations professionals may differ from those of many science communicators.

This report could not be and is not a comprehensive review of the scholarship on science communication. Instead, it synthesizes the most essential points (for which key sources are provided as examples), focusing primarily on issues and outcomes specified in the committee's statement of task (Box 1-1): the understanding, perception, acceptance, and use of science relating to topics that are often contentious. The report also does not directly address topics in formal science education, such as effective teaching methods or curricula related to communicating science, or informal science education.[2] Moreover, to identify the challenges of communicating and gaps in knowledge about the factors that affect people's understanding, perception, and use of science, the committee considered a wide range of science communication contexts, such as policy making, journalism, and communications that affect individual and public health. However, the report does not analyze each such context in detail. And while many topics related to the communication of science are important, not all are amenable to empirical study, and such topics are excluded from this report. For example, the important question of what

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[2] The following National Academies reports address informal science learning and communication: *Effective Chemistry Communication in Informal Environments* (National Academies of Sciences, Engineering, and Medicine, 2016a); and *Learning Science in Informal Environments* (National Research Council, 2009).

knowledge from science is ready to communicate and worth communicating outside of the scientific community involves ethical, practical, institutional, and academic cultural considerations that may not be addressable through a research agenda.

As is emphasized throughout this report, the science of science communication is an emergent field. The studies that make up the literature in this field are fragmented, issue-specific, and anchored in different disciplines, and often address the specific topic of science communication only obliquely. The committee reviewed those studies to gather suggestions on how to advance knowledge about effective science communication; those suggestions, however, are more tentative and speculative than those that would emerge from a mature and integrated field. The report ends with some ideas on how such integration might be accomplished in the future.

It is important to note as well that an assumption underlying the charge to the committee is that communicating science will have an effect on people's behavior and decisions. Although some research supports this assumption (e.g., Brewer et al., 2016), the evidence is not as rich as it needs to be. The impact of science communication on different types of decisions, in different contexts, is an empirical question worthy of substantial additional research. While the committee believes the scientific community has an obligation to communicate the results of its work to the rest of society, we emphasize that science alone is never a sufficient basis for resolving public debate about contentious issues. Moreover, the people concerned in a given science-related controversy hold many different opinions about the social, economic, moral, and ethical implications of an action, and these opinions all must be weighed in decisions about that issue (Yankelovich, 1991).

Finally, in addressing its charge to identify research with the potential to improve science communication, the committee took a broad view and did not interpret a lack of action consistent with science as necessarily resulting from a problem with science communication. How people define the problem of science communication will differ depending on their perspective. There may not be a science communication problem from the perspective of the audience if they understand the science and consider it in their decisions (i.e., use it), but behave in a manner inconsistent with the best available scientific evidence. For the communicator, this outcome may be considered a problem or a failure of science communication, depending on whether the goals of the communicator are to inform or persuade. Taking all these caveats into account, the committee believes the various disciplines that have studied aspects of science communication offer insights into its challenges. Moreover, these insights are ready to be advanced and to be integrated into a more coherent approach to communicating science for the benefit of society. It is the committee's hope that the research agenda proposed in this report will guide the field of science communication research, serving to assist science communicators and scientists whose work pertains to important societal issues. Their collective expertise will be needed to develop and test science-informed approaches to communicating science.

THE DIVERSITY OF SCIENCE COMMUNICATORS AND THEIR GOALS

Science is communicated by the scientific community (individual scientists, universities, and scientific associations), the media, advocacy organizations, think tanks, corporations, nonprofit research organizations, health professionals, and government agencies. Individuals also communicate science from their own perspectives as amateurs in their roles as science enthusiasts, issue advocates, or political commentators using social media, the web, and other venues.

Goals of Communicating Science

The most effective approach for communicating science will depend on the goal of the communication. The committee identified five broad and overlapping goals for science communication, each of which places quite different demands on the knowledge and skills of science communicators and their audiences and calls for its own distinct approach. These goals encompass a wide range of reasons for communicating, from informing audiences to motivating the actions of individuals, groups, or societies. The goals may be end points in themselves or objectives serving a larger goal that is the communicator's reason for communicating science.

First, the goal of science communication may be simply to share the findings and excitement of science. Many scientists wish to share their passion and intellectual excitement, believing that understanding of their work will enrich the lives of their fellow citizens. And since science typically is publicly supported, scientists may feel obliged to tell the public about the benefits for which it has paid.

A second goal of science communication may be to increase appreciation for science as a useful way of understanding and navigating the modern world. Although not fully tested, this goal assumes that people who have more knowledge about and are more comfortable with science, who have a general store of science-related information, and who value science and its role in accruing knowledge will be more willing and able to use scientific information (knowledge from science and how it is produced) in their decision making. Thus communicators may seek to increase people's general knowledge of science and of how it can improve quality of life and help in making decisions, and to expand the base of relevant information used routinely by the public—whether government officials, business leaders, or individual citizens. Integrating this knowledge with values and other relevant considerations can result in more informed decisions.

A third goal may be to increase knowledge and understanding of science related to a specific issue that requires a decision. In this case, communicators may seek to inform or educate people about the relevant facts from science, how those facts were derived, and what they mean for the decision. Communicators may seek to bring attention to a neglected issue or neglected aspects of an issue, or may wish to improve the quality of discourse on an issue—for example, through improved media coverage of the relevant science.

A fourth goal of science communication can be to influence people's opinions, behavior, and policy preferences when the weight of evidence clearly shows that some choices have consequences for public health, public safety, or some other societal concern. Communicators have, for example, worked to make people aware of the benefits of exercise, the dangers of smoking, and the importance of controlling one's blood pressure. In such cases, communicators may feel compelled both to inform people about scientific findings and to persuade people to change their behavior or make a particular policy choice. Communicators also may seek to influence public opinion—for example, on the benefits or risks of a medical procedure or technology—so as to rally support for a specific policy.

A fifth goal of science communication is to engage with diverse groups so their perspectives about science (particularly on contentious issues) can be considered in seeking solutions to societal problems that affect everyone. This goal sometimes is met through the formal process of public engagement, often invoked for societal decisions that are difficult scientifically, morally, and politically. Many modern technologies, such as human gene editing with CRISPR/Cas9 (a technology that makes it easy to target any DNA sequence for alteration), are characterized by (1) high levels of scientific, technological, and societal complexity that those without relevant expertise (including scientists working outside those areas of expertise) have difficulty understanding; (2) rapid translation ("bench to bedside") or transition from laboratory work to applications; and (3) a host of moral, ethical, political and societal implications that surround the application and practice of science (e.g., prenatal gene modifications in human embryos) (Scheufele, 2014). The need to address all these complexities has prompted leaders, both in and outside the scientific community, to call for scientists' greater engagement with the public (Ham, 2015; Leshner, 2003; Rowland, 1993).

The committee believes that while scientists have a duty to speak about their work, they have an equal duty to listen to the public so as to strengthen the quality of public discourse and increase the perceived and actual relevance of science to society. This kind of two-way public engagement may lead to insights about the problems that particular communities, or society as a whole, view as worth solving (Dietz, 2013a). It also can clarify what information society needs and wants from scientists. Science is influenced by the various professional and personal interests of scientists, their values and goals, and by various outside forces, such as political and industry concerns. For these and other practical or scientific reasons, such as limitations in the available scientific methods, science may not meet society's needs for information or speak to everyone's concerns. At a minimum, however, the public expects emerging science and technologies such as CRISPR to be discussed beyond the scientific community and monitored in a socially responsible way. Science communication as public engagement—by which we mean any communication between scientists and nonscientists, not just the formal process of public engagement—gives all stakeholders opportunities to discuss the potential risks, benefits, and consequences of a technology before it is developed or deployed[3]; can motivate attention to issues important to the public good; and ideally encourages civic participation and expression of views by all the diverse groups that are concerned with an issue.

Communication between scientists and the public can, of course, lead to controversy, but not all controversy around science is undesirable. No important societal decision is made solely on the basis of scientific evidence; such decisions also are made on the basis of facts, values, and understandings derived from other sources, such as personal or professional experience. Further, different people and communities are likely to weigh scientific input differently in accordance with their differing interests, experiences, and values. The process of public engagement can help build and sustain trust among stakeholders and aid in finding common ground through the negotiation of necessary trade-offs among divergent values, preferences, and needs (Sarewitz, 2015). How best to engage the public under different circumstances and on different issues is an important empirical question (as described in Chapter 3) that merits additional research. What is known now, though, is that public engagement often is essential for acceptable decisions about science-related controversies. It is clear as well that even when an issue does not involve a widely known controversy, science communication is more effective when scientists are willing and able to listen carefully and respectfully to different points of view.[4]

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[3] For the purposes of this report, "stakeholders" are defined as individuals or groups with an interest in or concern regarding an issue.

[4] This point has been made by many observers and is incorporated in recommendations made in National Academies reports on issues as varied as risk assessment, environmental assessment and decision making, climate change

Ethical Considerations

The decision to communicate science always involves an ethical component. Choices about what scientific evidence to communicate and when, how, and to whom are a reflection of values. This fact becomes especially salient when the science pertains to an individual decision or policy choice that is contentious.

The extent to which science communication should go beyond science to influence decisions (as in the fourth goal described above) has been and will continue to be debated (Ratner and Riis, 2014; Scheufele, 2007). In this debate, it is useful to distinguish between science communication per se and other types of communication that build on scientific evidence to influence behavior.

Science communication conveys scientific findings and methods and helps people assess how that information applies to a particular issue or situation. The debate centers on whether it is also appropriate for scientists to communicate science in order to persuade people to support a particular policy option or engage in a particular behavior. Doing so can involve bringing into the communication individual or societal values that lie outside the strict domain of science. Scientists disagree about where to draw the line in using science for this kind of persuasion.

Other types of communication may be designed to persuade but not depend solely on the underlying science that is the basis for the message. Examples are public health campaigns aimed at persuading teenagers to avoid smoking or binge drinking (Farrelly et al., 2009; Goldstein et al., 2008; Wakefield et al., 2003, 2010). These communications may convey the negative consequences of the targeted behaviors using emotional appeals, appeals to social norms, or other means shown to be effective in motivating behavior change, but may exclude or selectively present information from the underlying science.

As research in the field of science communication moves forward, it will be important to better understand and clarify these issues of the ethics of science communication and to promote ethical practices.[5]

THE SIMPLE—AND FALSE—MODEL OF SCIENCE COMMUNICATION

One model of science communication—the “deficit model”—is widely held, simple on the surface, and appealing, but frequently does not hold. This model depicts nonscientists simply as not yet informed about what science has to say on a topic. In this model, “the science" of an important question is settled, and stands immutable and clear to the experts; the task of communication is simply to explain the facts to the public. However, real-life science communication rarely if ever operates in this way.

First, although people do at times lack information from science that could be beneficial, the science on an issue by its very nature is seldom completely settled, and scientific “facts” not only are complex but also can often be interpreted in more than one way. Effective science communication conveys both complexity and nuance, and does so in a way that is understood by and useful to the audience to which it is directed.

Second, science communication often is not direct from scientist to audience, but

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research, and gene drives (National Academies of Sciences, Engineering, and Medicine, 2016b; National Research Council, 1996, 2008; see also as an example Rosa et al., 2010).

[5]Further discussion of ethical issues in science communication is found in Keohane et al. (2014) and Pielke (2007).

mediated by organizations, media, or other actors (who often select the audience themselves). This is part of the challenge of communicating science in the midst of controversy, when many competing voices are seeking to use the science for conflicting ends. Further, the way people interpret the information coming from various sources will be affected by such factors as their trust in the source, their existing knowledge of science, and their beliefs.

Third, although people may need to have more information or to have information presented more clearly, a focus on knowledge alone often is not sufficient for achieving communication goals. The deficit model is particularly insufficient when people may need to decide whether to take an action and what action to take. The model assumes that if an audience fails to act in a manner that some consider to be consistent with the scientific evidence, either the communication needs to be better crafted or delivered, or the audience is at fault for not knowing enough about the science or not being sufficiently appreciative. As noted earlier, however, people do not make decisions based solely on scientific information, but take values and other considerations into account. Thus it cannot be assumed that audiences that fail to act in accordance with the scientific evidence need more information, a better understanding of the information, or a greater appreciation of its scientific value. Effective science communication is aimed at helping people understand the science relevant to a decision and showing its relevance while recognizing that other factors will affect their actions.

Finally, the deficit model assumes that if a message about scientific information is well crafted for one audience, it should meet the needs of other audiences as well. In fact, effective science communication is affected by the context and requires engagement with different audiences in different places at different times, taking account of what they want to know and already know, understand, and believe.

ORGANIZATION OF THE REPORT

Chapter 2 of this report describes factors that contribute to the complexity of communicating scientific information and that need to be better understood regardless of whether the science pertains to an issue that is contentious in the public sphere. These factors include challenges inherent to scientific content, the individuals and groups that are the audiences for science communication, characteristics of the communicator, and the approaches used to communicate science.

When the science to be communicated relates to a public controversy, a better understanding of the factors discussed in Chapter 2 is insufficient for understanding the challenges of science communication. Chapter 3 briefly describes conditions that can cause science-related controversies to arise, and identifies factors that need to be better understood for effective communication of science related to contentious societal issues.

Chapter 4 identifies factors in the communication environment, such as those related to science journalism, the Internet, and social media, that are rapidly changing and affecting the way people seek or encounter information. These changes present both challenges and opportunities for communicators of science, whether they be individual scientists or organizations inside or outside the scientific community. The factors discussed in this chapter relate to communicating science regardless of whether the scientific information pertains to a contentious societal issue, although the discussion notes those that are especially relevant to science-related controversy.

Each of the above chapters contains questions for research surrounding the challenges of science communication. Chapter 5 summarizes these questions and describes a set of conceptual and methodological issues that need attention if an evidence base for communicating science is to be built. It also describes the committee's observations regarding needs for translational research, including forming partnerships between researchers and science communicators and building capacity to implement the proposed research agenda.

2
The Complexities of Communicating Science

Science communication is more complex than simply translating the jargon of science into language the public understands. Its complexity stems from the diversity and interconnectedness of its many elements, including the goals for communicating, the content being conveyed, the format in which it is presented, and the individuals and organizations involved. People approach science communication from their own starting points—a combination of expectations, knowledge, skills, beliefs, and values that are in turn shaped by broader social, political, and economic influences. Organizations and institutions involved in science communication add their own concerns and influences. Moreover, the communication landscape is changing dramatically in ways that offer unprecedented opportunities to communicate and connect with others but also pose many challenges, a topic addressed in detail in Chapter 4. A primary undertaking for those studying the science of science communication is to identify the key factors and best practices for effective science communication that anticipates and responds appropriately to this complexity. The issues discussed in this chapter apply to communicating science on almost any topic, regardless of whether the science is involved in a public controversy related to a contentious issue. The chapter that follows focuses in greater depth on the issues that matter in communicating science that relates in particular to topics that are contentious in the public sphere.

VARYING NEEDS FOR AND RESPONSES TO SCIENTIFIC INFORMATION

Few people outside the scientific community consume scientific information regularly (Boczkowski and Mitchelstein, 2013), although they encounter and benefit from science often in their everyday lives. Many people profess interest in science news, yet only 16 percent of the public say they follow news about science and technology "very closely" (Mitchell et al., 2016), a percentage that has remained below 18 percent since 2000 (National Science Board, 2014). Some people may encounter science as adults, and seek to make sense of it, only when it becomes important to a decision they must make as individuals or in the context of institutions in which they have a role—for example, as consumers, patients, parents, voters, or policy makers.

Making sense of scientific information is not easy. Consumers, for example, are faced with parsing complex and contradictory claims about the risks and benefits of fat, salt, added sugar, and genetically modified organisms (GMOs) in food. They must decide whether to agree with science-based advice about avoiding obesity, to listen to those who say the causes of obesity are not yet well understood, or to ignore science-based debates altogether. Likewise, patients must make choices about treatments and drugs—a task that often requires judging among contradictory claims about what "science says" and wrestling with inevitable uncertainties about the aftermath of any decision they make. Parents must choose whether to accept medically sound advice about vaccines. And policy makers must make decisions based on imperfect information and forecasts that invariably entail some uncertainties. Those decisions often relate to issues—

such as environmental regulation, the risks and benefits of new technologies, and food health and safety—that are deeply rooted in science.

Because the decisions they need to make will vary, individuals and groups will vary in what they need from science communication. They also will differ in the knowledge and skills, ways of interpreting information, and other characteristics that influence how they are likely to respond to scientific information. Communicators must therefore be responsive both to people's needs for scientific information and their ways of understanding, perceiving, and using science to make decisions. Adding to this complexity is that people's needs and opinions can change as their engagement with science increases. Thus, an effective science communication strategy will be iterative and adaptable. In particular, it will evolve over time based on lessons learned about what is and is not working, as well as shifting needs and opportunities.

THE NEED FOR FORMAL PUBLIC ENGAGEMENT

Although some goals of science communication can be achieved through one-way transmission of the information to an intended audience (as discussed later in this chapter), other goals are best achieved by the dialogue that occurs through formal public engagement.[1] Such goals as generating excitement, sharing information needed for a decision, and finding common ground among diverse stakeholders all lend themselves to public engagement as a communication strategy. In addition, public engagement can be an important way to learn about the concerns, questions, and needs of the audience(s) to which the information is targeted. A recent report of the National Academies of Sciences, Engineering, and Medicine (2016b) that includes a recommendation on public engagement for the emerging technology of gene editing provides a useful example of reasons for using such an approach. As gene editing science advances, it spurs many questions about the science and its applications, as well the ethics and governance of its use.

More generally, public engagement offers opportunities to facilitate transparency and informed consent among stakeholders and for each stakeholder to both learn from and teach others involved in the debate. An essential component of mutual teaching and learning is the opportunity to clarify one's beliefs and understanding, revise one's opinions, gain insight into the thinking of others, and articulate values amid uncertainty about the societal implications of a decision. A key benefit of such processes is building and maintaining trust through a fair, open, and transparent process. When scientists are transparent about any conflicts of interest, sources of funding, or important affiliations related to their work, public views of their integrity can be enhanced (National Academies of Sciences, Engineering, and Medicine, 2016b). When dealing with morally charged issues, however, the outcome may matter more to people than the fairness of the process (Earle and Siegrist, 2008). In these circumstances, simply ensuring a fair process may not be sufficient to foster trust and cooperation.

Engagement models increasingly are used in risk communication as an important way to address questions and conflicts related to the ethical, legal, and social issues that arise around science (e.g., National Academies of Sciences, Engineering, and Medicine, 2016b). It is also

[1]"Public engagement" can be defined as "seeking and facilitating the sharing and exchange of knowledge, perspectives, and preferences between or among groups who often have differences in expertise, power, and values" (National Academies of Sciences, Engineering, and Medicine, 2016b, p. 131). The specific terminology used for such activities may vary—some use the term "public participation" or "public deliberation," for example—but the concept remains the same.

argued that public participation is part of the role of an engaged citizenry in a democracy.[2] In the particular context of environmental decision making, research examining diverse traditions of public engagement—for example, on issues of Environmental Protection Agency (EPA) negotiated rulemaking, watershed management, climate change assessment, forest management, land use conflicts, and the cleanup of toxic waste sites—reveals practices associated with successful efforts. Among these are the use of processes that are inclusive, collaborative from the point of problem formulation, transparent, and characterized by good-faith communication (National Research Council, 2008). It should be noted, however, that most, although not all, of the available research focuses on public engagement efforts at the local to regional levels (National Research Council, 2008). Research is needed to determine effective structures and processes for engaging the public at larger scales, including the potential for online public engagement (Davies and Gangadharan, 2009). This need will become even more acute as nations cope with such problems as climate change that are global in scope (Corner and Pidgeon, 2010; Payne et al., 2015).

Public engagement is difficult to do well. The process of bringing together many stakeholders and publics is a challenging one that requires substantial preparation and support. Some critics suggest that low levels of knowledge about and attention to science, problematic group dynamics, and low levels of participation can make the process unproductive or even counterproductive in some cases (Binder et al., 2012; Merkle, 1996; Scheufele, 2012). Given that public participation may be especially useful when science is involved in controversy, Chapter 3 details principles of public engagement and additional needs for research.

Engaging the public may not appear to be essential in some situations, but there are both ethical and practical reasons, and in some cases legal mandates, for carrying out public participation (National Research Council, 2008). In science-related controversies, all three reasons for public engagement may be in play, making it important for research to attend to the design of engagement and deliberation processes involving science in a wide range of circumstances (see Chapter 3).

CHALLENGES POSED BY SCIENTIFIC CONTENT

The nature of the information or the state of the science itself can pose a challenge for communication. Science is expected to yield information that is useful to society—if not immediately, then eventually through a self-correcting and cumulative process. Science offers a unique, rule-governed method for producing reliable knowledge about the world. However, scientific findings often represent work in progress, are applicable only to particular contexts or populations, or are unsettled about questions to which the public wants clear answers. This section focuses on the uncertainty associated with scientific information and the challenges it poses for science communication.

Uncertainty has a number of sources that affect how it might be communicated. Researchers have developed ways to classify the types and sources of uncertainty.[3] Some sources

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[2]See, for example, Delli Carpini et al. (2004), which examines a range of outcomes that could be objectives of public deliberation and challenges of engagement to be addressed through research.

[3]For example, one typology identifies five main sources of uncertainty based on a review of the literature (Politi et al., 2007): (1) uncertainty about future outcomes (often called "risk" and operationalized as probabilities); (2) ambiguity, or uncertainty about the strength or validity of evidence about risks; (3) uncertainty about the personal significance of particular risks (e.g., their severity or timing); (4) uncertainty arising from the complexity of risk information (e.g., the multiplicity of risks and benefits or their instability over time); and (5) uncertainty resulting

are inherent to science and cut across all scientific disciplines, while others, such as the use of certain estimation models or methods of measurement, are specific to particular scientific fields. Uncertainty may relate to the complex nature of scientific information or to how people process such information. It can arise when predicting future outcomes using probabilistic evidence (risk) or when deciding about the degree to which scientific evidence applies to a particular context or has personal significance. Continued research can resolve some uncertainty by providing additional evidence, but in other cases, and especially with complex problems involving science, uncertainty will persist. Despite inherent uncertainties, science may inform decisions, but how to interpret the relevance of the information may be negotiated among consumers of scientific information, such as individual decision makers or groups of stakeholders (Dietz, 2013a).

As a rule, people dislike uncertainty and try to avoid ambiguity (Fischhoff and Kadvany, 2011; Kahneman, 2011). When faced with decisions, they often will choose the least vague alternative even when more vague alternatives have a better expected payoff (Ellsberg, 1961; Wallsten, 1990). Scientists, including medical professionals, may be reluctant to discuss the uncertainties of their work as well (Fischhoff, 2012; Politi et al., 2007). It is tempting, then, to avoid talking about uncertainty when communicating science, but this may be a mistake. Some audiences know that uncertainty exists and say they want to be informed about how certain scientific findings are (Frewer and Salter, 2007). It also is possible that failing to discuss uncertainty conveys a false sense of certainty that can undermine trust should the information have to be revised in light of new findings (Binder et al., 2016; Frewer and Salter, 2007).

Reactions to the various types of uncertainty differ among individuals depending on their characteristics and values (Peters, 2012a; Politi et al., 2007). In the absence of clear explanation, people may attribute uncertainty to a variety of incorrect sources (e.g., Dieckmann et al., 2015). Some, for example, may attribute uncertainty to poor science (Freudenburg et al., 2008; Johnson and Slovic, 1995). In some cases, communicating uncertainty can diminish perceived scientific authority (Funtowicz and Ravetz, 1992; see also National Research Council, 2014; Rosa et al., 2013). And for some patients in medical settings, receiving information about uncertainty can make them feel less satisfied with a decision (Han et al., 2011a; Politi et al., 2011). On the other hand, the communication of uncertainty in some contexts promotes a sense of transparency that can foster trust (Johnson and Slovic, 1995). Clear information about uncertainty also can be helpful to decision makers weighing risk (Fischhoff and Davis, 2014; Joslyn and LeClerc, 2012; Joslyn et al., 2013). These findings suggest that audiences vary in their desire for and responses to information about uncertainty. One form of uncertainty concerns conflicting evidence or confusion about how much evidence supports different points of view. Scientists themselves may be uncertain and disagree about how to interpret scientific evidence. Such real or perceived conflicts can be quite disconcerting to audiences (Politi et al., 2011). The weight of evidence, or the degree to which facts and causal explanations regarding a particular issue are well established, may be insufficient to support a conclusion in cases in which the science is emergent, uncertain, or contested. Examples include the causes and impacts of obesity, the relative merits of technologies for responding to climate change (such as carbon capture and storage and solar radiation management), the social and health impacts of "vaping," and the academic consequences of introducing more market-like policies in education (such as vouchers

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from ignorance. For another example of classifications of uncertainty, see Han et al. (2011b). For further discussion of scientific uncertainty as part of decision making, see Institute of Medicine (2013, 2014) and National Research Council (2006).

or charter schools). In addition, while the science may be relatively certain in one context, its application to another context, particularly to a complex local problem such as the contamination of a water supply or the implications of climate change, may increase scientific uncertainty.

With some issues, on the other hand, the weight of evidence leads to broad agreement within the scientific community. Such issues include the human contribution to climate change, the health benefits of vaccines, and the validity of evolutionary theory. In these cases, varying numbers of people remain unsure or unconvinced about the weight of evidence behind the assertions of the scientific community. In the case of climate change, one study found that communication that conveys a high degree of scientific consensus on an issue can increase people's acknowledgment of that consensus (van der Linden et al., 2015), although it is unclear whether accepting scientific consensus influences people's attitudes or beliefs about an issue (Kahan, 2016) or support for particular policies (Kahan, 2016; McCright et al., 2013a). Further, some evidence indicates that political views influence people's perceptions about scientific consensus on climate change (e.g., McCright et al., 2016). More remains to be learned about how audiences vary in their response to information about consensus on various issues.

National Academies reports have examined how to represent the level of agreement about scientific findings in the scientific community and the approaches that may be effective in different contexts.[4] The Intergovernmental Panel on Climate Change (IPCC) employed labels to characterize confidence in scientific claims using the type, amount, quality, and consistency of the data, in addition to presenting information with statistics and probabilistic terms. However, people disagree widely about what verbal probability terms mean (Teigen and Brun, 2003). Thus, attempts to legislate such translations, such as that made by the IPCC, have not succeeded (Budescu et al., 2014; Teigen, 2014). The inclusion of numerical probabilities alongside verbal probabilities appears to result in more accurate interpretations than use of either alone (Budescu et al., 2012, 2014; Sinayev et al., 2015). Ultimately, the effectiveness of communications about uncertainty depends on the decision context (Fischhoff and Davis, 2014; Savelli and Joslyn, 2013; see also the discussion in Zikmund-Fisher, 2013) and the clarity of the communication format (Institute of Medicine, 2014; Spiegelhalter et al., 2011; Stephens et al., 2012; Taylor et al., 2015).

Research is needed to identify best practices for communicating the uncertainties of science in ways that convey the weight of evidence and speak to the particular questions people may have about specific sources of scientific uncertainty surrounding an issue. Formats are needed for communicating uncertainty to individuals or groups to support the use of scientific information as part of decision making, as are approaches that can be used to communicate on a large scale.

KEY INDIVIDUAL AND ORGANIZATIONAL FACTORS: DIFFERENT AUDIENCES, DIFFERENT NEEDS

A responsive orientation to science communication means that the needs, abilities, perspectives, and constraints of the audiences are considered in the approach taken to communicating. This section addresses how three key aspects of audiences affect science communication: (1) prior knowledge of science, (2) ability to understand numeric information, and (3) ways of interpreting new information. Together, these factors help explain why the same information from science can be understood and perceived so differently among different

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[4] Examples include discussions of vaccine-adverse events, as in Institute of Medicine (1994, 2002).

individuals. While the influences discussed here are evident for many people in the contexts within which they have been studied, further study is needed to determine the importance of each of these influences to communicating science to specific audiences in particular contexts to achieve specific goals. Research also is needed to determine their particular importance when a societal issue is contentious or when the science itself is controversial.

Prior Knowledge of Science: Debunking the "Deficit Model"

A long-standing question among science communicators is whether people have sufficient understanding and skills, such as science literacy, to make sense of science communication and to express their views as informed citizens on issues involving science. According to a recent National Academies report on the topic, science literacy can be broadly defined as having "some level of familiarity with the enterprise and practice of science" (National Academies of Sciences, Engineering, and Medicine, 2016c). A central theme of that report is that science literacy can be considered a characteristic not only of individuals but of communities and societies as well.)

Knowledge levels among the general public, if measured as simple recall of scientific facts, have remained fairly high over time (Scheufele, 2013). At the same time, knowledge of scientific methods and thinking appears to be less widespread. Only one in four Americans (26 percent) in 2014 could explain "what it means to study something scientifically," and only half of Americans (53 percent) had a correct understanding of randomized controlled experiments (National Science Board, 2016a).

For most people, formal science education ends in high school. Yet science continues to evolve, producing new information, discoveries, and technologies. Therefore, science education is seen as a lifelong process of learning that occurs across settings (Dierking and Falk, 2016). Most studies show that science literacy is strongly associated with level of education (National Science Board, 2016a), and only one-third (32.5 percent) of Americans over age 25 hold a bachelor's or advanced degree (Ryan and Bauman, 2016). According to the National Science Board (2016b), moreover, as of 2013 only about 21.1 million adults in the United States had attained a bachelor's or higher-level degree in a field of study involving science or engineering—about 9 percent of the 226.4 million Americans over age 21 (U.S. Census Bureau, 2013). Therefore, only about 1 in 10 American adults have had formal education as scientists or engineers.

The deficit model would predict that the more knowledge one has about science and the way it works, the more positive one's attitudes toward science will be and the more consistent one's decisions with scientific evidence. Yet a growing body of research on the links between amount of scientific knowledge and attitudes toward science underscores that this is not a simple and direct relationship. Rather, a person's characteristics, background, values and beliefs, and cues from mass media shape the linkage between general scientific knowledge and attitudes (Brossard et al., 2005; Ho et al., 2008; Scheufele and Lewenstein, 2005). Once these factors are taken into account, the relationship between knowledge and attitudes across studies is either weakly positive, nonexistent, or even negative (Allum et al., 2008; National Academies of Sciences, Engineering, and Medicine, 2016c) (see the more detailed discussion of this point in Chapter 3). These findings point to the importance of testing individual messages carefully before they are used. Moreover, knowledge is not a prerequisite for holding an opinion on a topic, which may explain in part the lack of relationship between knowledge and attitudes.

Surveys show, for example, that a vast majority of people favor labeling GMOs in food, while many fewer people demonstrate knowledge about them (McFadden and Lusk, 2016).

Ability to Understand Numeric Information

Numerical information and concepts are often an important part of communicating scientific information, including scientific uncertainty. The understanding and use of mathematical concepts and numeric information often is referred to as “numeracy.” Many people, however, have difficulty understanding the quantitative and probabilistic information that frequently is the language of science. Problems with numeracy frequently affect even scientists outside of their areas of expertise. Thus when communication strategies need to convey quantities, rates, and probabilities, careful attention is required to the substantial body of research on how people process, and commonly misunderstand, such information, as well as to the best available tools for presenting it, as described later in this chapter.

Communication that take people’s challenges with numeracy into account are more effective at improving understanding of the information presented, and in the health context, even at improving health outcomes (e.g., Peters et al., 2007). A large research literature on health decisions suggests the following steps for presenting numeric information so that it is understood and used effectively (see Institute of Medicine, 2014): (1) providing such information (i.e., not avoiding numbers); (2) reducing the cognitive effort required from the patient or consumer and requiring fewer inferences; (3) explaining what the numbers mean, particularly when the numeric information is unfamiliar to the audience; and (4) drawing attention to important information. Research outside the health domain is needed to determine how numeric information, such as uncertainty, can be presented in a way that facilitates comprehension and use of the information across individuals, including those with lower numeracy. (A few systematic studies in this area do exist—for example, in finance [Soll et al., 2012] and in environmental domains [Hart, 2013; Markowitz et al., 2013; Myers et al., 2015].)

Ways of Interpreting New Information

As noted earlier, beyond knowledge and skills for interpreting scientific information, people hold a variety of beliefs, values, and ways of understanding the world that shape their interpretations of new information. These predispositions are discussed below; a more detailed discussion of the roles of beliefs and values is included in Chapter 3 because of the central role they play in communicating science related to contentious societal issues.

Beliefs People Use to Explain the World

One approach to understanding variation in how people interpret scientific information focuses on their “mental models”—the sets of beliefs they hold to explain how the world works (Bruine de Bruin and Bostrom, 2013). People who are deeply versed in the methods, theories, and facts of a particular scientific discipline use mental models quite different from those of nonexperts (Chowdhury et al., 2012). Nonexperts tend to apply multiple and often idiosyncratic explanations for a phenomenon. They also rely on metaphors and analogies to draw inferences (Bostrom, 2008) and often focus on the less relevant aspects of a problem or phenomenon (Chi et al., 1981; Downs et al., 2008).

People apply these ideas to their interpretations of new information, and their prior mental models tend to be resistant to change even when they encounter information to the contrary. Understanding people's mental models can help communicators identify gaps in what people know, as well as misinformation or conceptions that affect how they make sense of an issue. With these insights, communicators could, for example, design approaches (such as framing, discussed later in this chapter) for making information more accessible to people, who could then use it in making decisions (Nisbet, 2014; Scheufele and Scheufele, 2010). The role of beliefs in science communication when science is involved in public controversy is discussed further in Chapter 3.

Mental Shortcuts: Heuristics, Emotion, and Motivated Reasoning

At times communicators may expect people to evaluate scientific uncertainty and other evidence based on full knowledge and understanding of the information they receive, but that simply is not how the human mind appears to work when confronted with complexity. Instead, when trying to interpret scientific uncertainty and other complex information, people reduce mental effort by using a variety of heuristics or mental shortcuts to evaluate the evidence (Tversky and Kahneman, 1974). These shortcuts are usually adaptive, allowing people to decide quickly and efficiently how likely or how dangerous something is. Trust in, or deference to, scientific authority is an example of a reasonable shortcut people use for forming opinions or attitudes about science (Brossard and Nisbet, 2007). Yet shortcuts can bias interpretations of science, especially scientific uncertainty (Bruine de Bruin et al., 2007). For example, they influence understandings, memories, and reactions so that people pay more attention to, or weight more heavily, information that is consistent with their preexisting feelings about a subject. People also have a propensity to perceive that information they encounter frequently is more true or important than information they have encountered less often, even when that inference is incorrect (Fazio et al., 2015).

The use of emotions, in particular, is a critical mental shortcut in understanding and reacting to scientific information (Slovic et al., 2004). Like other mental shortcuts, emotions generally are helpful because they quickly inform perceptions of risks and benefits (e.g., "If I feel bad about a hazard, then it must be high in risk and low in benefit" [Finucane et al., 2000]). Emotional reactions motivate people to act and guide them to think more about important risk information in ways that would not occur without those emotions (Evans et al., 2015). But these same adaptive mental shortcuts also can bias reactions to science. As a result of these shortcuts, for instance, people's initial emotional reactions to new information can persist, shaping and limiting how they respond to subsequent information (Bruine de Bruin and Wong-Parodi, 2014). These shortcuts also may cause people generally to attend more to negative than to positive information (Shaffer and Zikmund-Fisher, 2012).

Furthermore, people with lower numeracy are more likely to rely on these heuristics when engaging in complex judgments and decisions such as those that involve science, and especially scientific uncertainty (Peters et al., 2006; Sinayev and Peters, 2015). They also rely more on narratives and the way information is presented in particular lights (discussed below) instead of applying the probabilities and other numbers critical to understanding science (Peters, 2012a). Of course, highly numerate individuals also sometimes misunderstand numeric information and use heuristic processing, but to a lesser degree (Peters et al., 2007; Chapman and Liu, 2009). Careful attention to how scientific uncertainty and other numbers are presented can reduce the use of heuristics and increase understanding and use of provided numbers, especially among the less numerate (Institute of Medicine, 2014).

One form of mental shortcut is motivated reasoning, defined as the "systematic biasing of judgments in favor of one's immediately accessible beliefs and feelings [that is] built into the basic architecture of information processing mechanisms of the brain" (Lodge and Taber, 2013, p. 24).[5] Most, and perhaps all, people possess this natural reluctance to accept facts, evidence, and arguments that contradict the positions they hold. Because individuals tend to engage in motivated reasoning, the source of communication about a science-related topic and how that information is presented are likely to trigger specific associative pathways and patterns of thinking that will influence their attention to and interpretation of all subsequent information (Kraft et al., 2015).

Cognitive Dissonance

Cognitive dissonance is the feeling of discomfort that arises from holding two conflicting thoughts or a thought that is discrepant with one's behavior (Festinger and Carlsmith, 1959). The desire to end this discomfort is a strong motivator to resolve the conflict by changing either one's behavior or one's thinking. Cognitive dissonance can lead to attempts to justify one's existing behavior or way of thinking, making a decision or attitude resistant to change. Indeed, people tend to doubt or reject expert persuasive messages that threaten or could lead to restrictions on freedoms or social activities they value (Byrne and Hart, 2009). For this reason, communicators need to be careful not to question or assault people's values, and alternative information needs to be provided in a nonthreatening way.

SOCIAL INFLUENCES ON HOW PEOPLE INTERPRET SCIENCE

Little research has examined directly how groups and social contexts (e.g., social networks, group norms, group membership, social identity) in which people are situated influence science communication (Bliuc et al., 2015; Pearson and Schuldt, 2015). Research is therefore needed on how groups (ranging from local governments to civic associations to planning boards) may differ in their attentiveness or response to science communication and the mechanisms by which different groups can best be reached and involved as audiences or participants in the science communication process. For example, a National Academies study focused on science literacy proposes that "community-held" science literacy is a concept to be explored in future research (National Academies of Sciences, Engineering, and Medicine, 2016c). Research taking social influences into account could take advantage of statistical and data collection approaches that could provide a more nuanced understanding of group-level influences than currently exists (e.g., Contractor and DeChurch, 2014).

A particular need is a better understanding of groups that are underrepresented as audiences or participants in many traditional forms of science communication. Groups that may differ in their attentiveness or response to science communication may be distinguished by race, ethnicity, language status, income, or education level, and their responses may differ as a result of differences in conditions, norms, beliefs, or experiences. Some of these disparities with

[5] Many social science disciplines have studied this phenomenon, although the terms used for it differ. In some areas of psychology and political science, for example, it is called "biased assimilation," while in decision sciences it is termed "Bayesian updating" (e.g., Lord et al., 1979; Munro and Ditto, 1997; Munro et al., 2002).

respect to knowledge acquisition—often called "knowledge gaps"—are discussed in Chapter 4. In the health domain, evidence suggests such gaps extend to disparities in the ability to access information sources and the capacity to process information—which may, for example, be limited by language barriers—and the ability to act on health information—resulting, for example, from a lack of health insurance (Viswanath, 2006).

In other research on group differences, whites and nonwhite racial and ethnic groups are divided along different political lines with regard to specific topics such as climate change (McCright et al., 2016; Schuldt and Pearson, 2016) and receptiveness to new medical technologies (Groeneveld et al., 2006), and whites relative to nonwhites generally are more deferential to scientific expertise (Blank and Shaw, 2015). In some instances, these differences may be rooted in objective experiences with science, either contemporary or historical. High-profile abuses, such as the Tuskegee syphilis study, appear to have contributed to higher levels of mistrust of science among African Americans, although the precise nature of the linkage is uncertain (Freimuth et al., 2001), as is the extent of this mistrust. Science communicators at a minimum need to be aware that messages from science may be heard differently by different groups and that certain communication channels, modes, messengers, or messages are likely to be effective for communicating science with some groups and not others.

PRESENTING INFORMATION IN DIFFERENT FORMS

The way in which scientific information is presented also affects how people interpret it. Whereas formally engaging the public, as discussed earlier, fosters multiway communication, the approaches that follow are used more commonly, though not exclusively, in one-way communication about science.

Framing

Framing is casting information in a certain light to influence what people think, believe, or do. Framing often is used to communicate that an issue is a priority or a problem, who or what might be responsible for it, and what should be done about it (Iyengar, 1991, 1996). Climate change, for example, could be presented as a grave environmental risk, as a public health risk, or as an opportunity for innovation and economic development (Nisbet and Scheufele, 2009). Frames are used to communicate in a wide range of channels that include conversation, public debate, and media reports. They also are used to deliver persuasive messages such as those intended to further public health–related goals. Marketing professionals and researchers have long employed and studied approaches to communicating in media, including online environments, to persuade others, including efforts to adopt healthy practices (see, for example, Kotler and Keller, 2015; LeFebvre, 2013; Stewart, 2014). While the methods and tools from these fields may be useful for science communication, any practices from these fields would need to be tested in the context of science communication where persuasion was the goal.

Research suggests that such frames are likely to influence judgments about complex science-related debates when they are relevant to an individual's existing ways of organizing, thinking about, and interpreting the world (Nisbet and Scheufele, 2009; Scheufele, 2000). In the case of GMOs, for instance, information framed in terms of social progress and improving quality of life may fit one individual's way of thinking about the issue, while a frame that focuses on public accountability and right to know may appeal to another (Nisbet and Scheufele, 2009).[6]

Much of the research on framing to date has involved experiments comparing equivalent messages that convey either gains or losses (gain/loss framing) associated with an action or lack thereof. Other research compares the effects on audiences of science reports cast with different emphases (emphasis framing). Some information, for example, may be described in terms of local or personalized stories, while other descriptions offer general knowledge or statistical facts.

Gain/Loss Framing

Hundreds of studies across a range of fields have tested the ability of gain/loss framing strategies to influence specific types of behaviors. Reviews of these studies paint a contradictory, uncertain picture. For example, whether framing in terms of gains or losses is more effective appears to vary depending on the type of message—that is, for instance, whether the message is intended to encourage behaviors to maintain health or detect illness or actions to mitigate climate change (Rothman and Salovey, 1997; Gallagher and Updegraff, 2012).

Meta-analyses of studies testing the effects of gain/loss framing on health prevention attitudes, intentions, and behaviors, including safe sex and vaccination, find either weak or no effects on attitudes and intentions and limited effects on behaviors (O'Keefe and Jensen, 2007; O'Keefe and Nan, 2012). Within health promotion research, effects of framing vary depending on whether the message is intended to affect behaviors related to skin cancer prevention, smoking cessation, and physical activity (for which small but potentially important effects were found), or to affect attitudes toward or intentions to seek out screening to detect illness (which showed no effects according to meta-analysis [Gallagher and Updegraff, 2012]). Similar patterns of mixed findings have been found in research on climate change communication. Messages framed in terms of environmental and economic gains rather than losses, for example, have led to greater support for mitigation-related actions (Spence and Pidgeon, 2010; Hurlstone et al., 2014). Other research has found no influence on attitudes when messages emphasize benefits over risks (Bernauer and McGrath, 2016).

Emphasis Framing

In this line of research, frames are rendered as interpretive story lines that communicate what is at stake in a complex policy debate and why the issue matters. The story lines influence decisions by offering different trains of thought, each of which emphasizes one dimension of a complex issue over another—for example, pointing to new applications of an emerging science such as nanotechnology instead of the potential risks and benefits (Anderson et al., 2013). A common type of experiment in emphasis framing compares episodic and thematic framing: scientific information is cast either in terms of specific personalized stories (episodes) or more broadly (themes). Episodic framing, for example, might focus on the effects that foregoing

[6] This discussion focuses on intentional framing, although framing is always present in messages even if the communicator's use of a frame is not intentional or intended to influence people. The use of framing by scientists is a matter of debate. One issue concerns how to choose a frame that does not inadvertently convey misinformation (similar to the concern scientists can have about the use of analogies to communicate science). Another concern is whether scientists should communicate to influence people, as discussed in Chapter 1. For further discussion about the ethics of framing in science communication, see Keohane et al. (2014).

vaccination had on a particular family and their children's health. Thematic framing, in contrast, might present statistics about the likelihood of adverse health effects should vaccination rates drop below certain levels. As with gain/loss framing, however, evidence for the effectiveness of either approach in changing attitudes or the degree of support for a particular action is mixed. Also mixed are findings on framing complex science-related problems such as obesity or climate change in terms of personalized stories as a persuasive strategy for encouraging behaviors or building support for policy actions. Some studies indicate that this approach is ineffective (Hart, 2010; Coleman et al., 2011), while others show that narrative accounts can lead to greater support for particular policies or intention to vaccinate (Dahlstrom, 2014; Niederdeppe et al., 2014; Nan et al., 2015).

Some argue that framing as a concept has become too broad and overlaps too much with other effects of the media on people's decisions about the issues and ways of thinking that are salient to them (Cacciatore et al., 2016) (see Chapter 4). This conceptual murkiness may be one explanation for the unclear findings noted above. Results also may appear mixed because the research has not been systematic within or across the disciplines that study framing. It would be fruitful for future experimental research to determine the effects of particular kinds of frames on certain types of outcomes and to assess the degree to which these effects generalize to communicating about a range of issues.

Knowledge of framing effects could be enhanced with national samples and studies of framing in which people were subjected to competing messages from social media and other sources (McCright et al., 2015; Nisbet et al., 2013), as is typical of complex, real-life communication environments (see Chapter 4). Research also is needed to determine the extent to which framing of an issue matters and when it is best done. Important as well is to determine effective ways of continually reframing an issue in response to changes in people's perceptions and understandings, or misunderstandings, about science as a public controversy evolves.

Helping Audiences Understand Uncertainty and Complexity

Research has evaluated various ways of presenting information for greater understanding of complexity and uncertainty. Science communicators frequently use narratives—information, including complicated numeric or statistical information, presented in the form of a story—to help explain complex issues (Entwistle et al., 2011; Reyna and Brainerd, 1991; Shaffer and Zikmund-Fisher, 2012). Narratives can increase audience engagement with and attention to science communication, and be easier to remember and process (Bekker et al., 2013; Dahlstrom, 2014; Kanouse et al., 2016; Winterbottom et al., 2008) relative to traditional forms of scientific communication. However, the use of narratives to promote understanding in science communication remains understudied (Dahlstrom, 2014). A common concern about narratives among experts is that they can sway people from using the presented statistical information (Downs et al., 2008; Kanouse et al., 2016; Shaffer and Zikmund-Fisher, 2012; Winterbottom and Bekker, 2009).

As might be expected, people who are low on measures of numeracy prefer and are more influenced by explanations that are presented as stories than by those that involve numbers (Dieckmann et al., 2009). People with higher numeracy are less sensitive to how information is presented (Institute of Medicine, 2014). This finding is in line with other evidence suggesting that people with lower numeric skills tend to focus on narrative and other non-numeric information (e.g., information frames) even when it is irrelevant to the point, while ignoring relevant numbers (see Peters, 2012a; Reyna et al., 2009; Volk et al., 2008).

Despite the difficulty that numeric information poses for many people, it is sometimes the best way to promote understanding of the science, as experiments in communication about climate change, health, and the environment have demonstrated (Budescu et al., 2009; Myers et al., 2015; Peters et al., 2014). People who receive numeric information about scientific consensus on climate change, for example, estimate that consensus more in line with reality relative to those given non-numeric descriptive information (Myers et al., 2015).

THE SPECIAL CASE OF POLICY MAKER AUDIENCES

Policy making occurs in a complex system that includes formal structures and procedures and a broad range of policy networks, actors, and organizations that affect how people involved in the system encounter and interpret information. When policy issues have substantial scientific content, policy networks involved with the issue will usually include individuals and organizations with concomitant scientific expertise (Dietz and Rycroft, 1987; Dietz et al., 1989). Nonetheless, biases in reasoning and assimilation of new information and the tendency of people to network and bond with similar others can prevent the spread and use of information across networks (Henry and Vollan, 2014). (For further discussion of networks in science communication, see Chapter 4.)

Research has shown that the use of science in policy making is not a straightforward process involving a simple, traceable relationship between the provision of information and a specific decision. Even when policy makers have access to and understand all the relevant sources of information, they will not necessarily weigh science heavily or use it to identify and select among policy options (e.g., National Research Council, 2012; Weiss, 1988). There is a paucity of evidence, however, on effective practices and structures for affecting policy makers' understanding, perception, and use of science (National Research Council, 2012).

As discussed above with respect to decision making generally, policy makers do not rely solely on the scientific information relevant to an issue. Values and personal interests operate at each stage of the policy process, from agenda setting to policy formulation, budgeting, policy implementation, policy monitoring, and policy evaluation. Policy makers, like everyone else, use mental shortcuts discussed earlier that affect their attention to and use of information, including when making decisions (Carnevale et al., 2011). Overall, evidence on the impact of science communication on policy decisions is still sparse and murky. A broader literature examines how the structure of policy networks influences and is influenced by values and beliefs, but research is only beginning to address scientific understanding per se (Frank et al., 2012; Henry, 2011; Henry et al., 2011). One reason for this lack of evidence is that it is difficult to study and assess how policy makers make sense of, are affected by, and use information from science. Policy makers vary in their science-related abilities and knowledge, and in some respects are influenced by the same factors that affect everyone's understanding and perceptions of science. For example, like most people (including scientists themselves who encounter scientific evidence outside their own areas of expertise), they need to have scientific information interpreted and validated by trusted sources.

In a complex policy-making environment, it is almost impossible to know with any certainty that a specific decision made by an individual or group resulted from a specific encounter with relevant information. From the perspective of science, a goal of communicating with policy makers is to ensure that relevant scientific information is received and understood by those who may use it to make a decision. From this perspective, it may be sufficient to assess the effectiveness of science communication by documenting that the information was received, understood, shared, or discussed in a formal policy process (e.g., formal arguments, congressional testimony, public deliberations) (National Research Council, 2012). Research is needed to determine how science communication can influence these processes and how they are affected by science-related controversy.

Both individuals and organizations play a role in aggregating, diffusing, and interpreting scientific information for use by policy makers. The remainder of this section reviews several approaches to science communication within the policy-making context.

Aggregation and Translation

One approach to communicating science to policy makers involves one-way communication, such as issue briefs or websites. Examples of communicators using this approach from the health and education arenas include the Cochrane Collaboration, the Campbell Collaboration, and the What Works Clearinghouse. These organizations gather evidence about effective interventions that they communicate through research summaries, lists, or guidelines so that policy makers can readily grasp the relevance of the information to a decision or task at hand. It is unclear, however, whether such translation efforts enhance the understanding or use of evidence-based practices (Ginsburg and Smith, 2016; Glasgow and Emmons, 2007; Green and Siefert, 2005; Lavis, 2006; Slavin, 2006).

Brokering

Another organized approach to communicating science occurs in the form of brokering. A broker in this context is an intermediary (an organization or a person) that bridges science and policy making by providing information while developing relationships within networks and linking those who produce knowledge with those who may use it. Brokering may include facilitating agenda setting and other conversations among multiple stakeholders regarding complex or contentious societal problems that involve science. Although individuals may serve as brokers, “boundary organizations” also play this role and have been identified as critical to increasing evidence-informed decision making (Dobbins et al., 2009). Boundary organizations are entities that facilitate the flow of information among researchers, stakeholders, and policy makers while refraining from advocating policy positions (Bednarek et al., 2016). They may be think tanks, university-based policy centers, or other nonprofit research and policy organizations. Such organizations are able to devote the needed time, expertise, and resources to the task, and have been particularly useful in connecting researchers and policy makers (Bednarek et al., 2016). A small emerging literature, consisting mainly of case studies of established policy networks, documents the processes, associated outcomes, and conditions for the success of boundary organizations (e.g., Am, 2013; Bednarek et al., 2016; Leith et al., 2016). Other emerging research examines how information flows and evolves as it is used by bridging organizations and in policy networks (Bidwell et al., 2013; Frank et al., 2012; Henry and Vollan, 2014; Lemos et al., 2014; Lubienski et al., 2014). Research is needed to determine how science is best communicated to achieve particular goals in the context of such networks and organizations. What, for example, is the effect of boundary organizations on the quality or outcomes of policy discussions of science-related issues?

Partnerships

Another approach is aimed at fostering communication by positioning data and evidence as complements, not alternatives, to the professional knowledge, values, and practical experience of policy makers and the officials who implement the policies. Through partnerships entailing sustained interaction with members of the policy system and the practitioner community, researchers come to understand local needs and circumstances, while policy makers and practitioners gain a better understanding of the process of research and their role in it. These ongoing relationships among researchers, policy makers, and practitioners can benefit science communication directly by building understanding of science and trust (discussed further below) that can thwart attempts to draw science into public controversy (Bryk et al., 2011; Cohen-Vogel et al., 2015; Tseng, 2012). The formation of partnerships—such as those that have been established for education (e.g., Coburn and Penuel, 2016), criminal justice (Sullivan et al., 2013), and health (Kothari et al., 2011)—thus can increase the usefulness of research to policy decisions. In some cases, these partnerships take the form of assessments of the state of scientific knowledge related to a key policy issue, such as climate change (Morgan et al., 2005; National Research Council, 2007). Because participants in a partnership work together regularly and come to know one another, they learn to trust each other and communicate effectively. This trust and ease of communication makes it possible to design research agendas and protocols that are responsive to the needs and goals of all parties, and makes the communication of research findings a natural and ongoing element of working life for each group. As a result, both "good news" and "bad news" from the research may be accepted, built upon, and used. Most existing information about such partnerships is descriptive, however, and research is needed on the conditions of success in communicating science by diverse types of partnerships.

An exception is the health sciences, in which a significant body of research has developed in the area of dissemination and implementation science, with the aim of devising strategies to facilitate the effective incorporation of evidence-based practices (e.g., behavioral interventions, diagnostic treatments) into public health, clinical practice, and community settings (Brownson et al., 2012). The dissemination component of the research has focused on diffusing information about evidence-based interventions. The implementation research has proceeded with the recognition that a one-way flow of information in the form of a recommendation or guideline is insufficient to ensure use of an evidence-based practice. Thus the research has included a focus on partnerships between researchers and practitioners, on community-based participatory research, and on the engagement of multiple stakeholders and users of an intervention throughout the development and implementation process. Other scientific disciplines have similar challenges with communicating science, but use diverse methods and language for studying the problem. In such fields as health science in which evidence is accruing, there is a need for comprehensive reviews of the factors that affect the communication of science so those findings can be applied and shared with other fields that communicate science for similar reasons in similar contexts.

TRUST AND CREDIBILITY OF SCIENCE COMMUNICATION

The types and numbers of people and organizations that are communicating about science are increasing, spurred in part by the growth of online communication and accompanied by a decline in the coverage of science in mainstream media. These communicators include scientists themselves, health care providers, government sources, media, industry, a range of organizations, and individual citizens. Many interpersonal factors affect communication between people. For science, however, whose product is evidence-based information, being trusted as a source of valid and useful information is particularly critical. The following sections describe the factors that affect trust in science communication and the types of outcomes of that communication that are affected by trust.

Factors That Affect Trust and Credibility

In science communication, the audience decides whether communicators as sources of information, or the institutions they represent, are credible and trustworthy and credible. People use these assessments to decide what information to pay attention to and often, what to think about that information. While there is no widely accepted definition of trust, many conceptualizations include variations of three elements: integrity (those who can be trusted are fair and just), dependability (they can be relied upon to do what they say they will do), and competence (the ability to do what they say they will do (Hon and Grunig, 1999; Rahn and Transue, 1998; Roduta-Roberts et al., 2011). Still others describe trust as a relationship in which both parties are willing to take risks and accept uncertainty about what their future interactions will be like, and others as a willingness to be vulnerable (Colquitt and Rodell, 2011; Earle, 2010; Henry and Dietz, 2011). Some see trust as a decision to give someone the benefit of the doubt (based on assessment of their future intentions) (Earle, 2010). And some conceptualizations of trust emphasize deference to or a reliance on decision makers or others in the scientific community to know and do what is best (Brossard and Nisbet, 2007; Siegrist et al., 2000). No organizations, institutions, or experts are universally trusted on all issues. People often make judgments about trustworthiness in relation to the information being conveyed (Chryssochoidis et al., 2009; Lang and Hallman, 2005), and they will not necessarily deem a particular source to be trustworthy and competent across topics.

People generally rely on two kinds of social information to determine whom they will believe and find credible on scientific issues: (1) having common interests, defined as the perception that the communicator and listener desire the same outcome from the communication, and (2) perceived expertise (Lupia, 2013; Siegrist et al., 2000; Suhay and Druckman, 2015). Because actual expertise, such as scientific credentials, matters less than perceived expertise (Lupia, 2013), scientists do not automatically have credibility with many audiences. Credibility is attributed by the listener, not a fixed characteristic of the speaker. As with trust, it often includes a dimension focused on the perceived honesty and openness of the communicator (Renn and Levine, 1991). Audiences also may be more likely to find a source credible if they believe they can learn from that source (Lupia, 2013).

In general, the public has consistently had stable and high levels of trust in scientists (Gauchat, 2011, 2012; National Science Board, 2016a; Pew Research Center, 2015a). For information about GMOs, for example, scientists at universities and in industry, universities, and medical professionals are seen as relatively trustworthy sources of information, although industry sources are seen as least trustworthy (Corley et al., 2012; Ipsos MORI Social Research Institute, 2014; Lang and Hallman, 2005; Nisbet and Markowitz, 2016). However, the kinds of scientific sources an individual trusts also vary with that person's political ideology (McCright et al., 2013b). With respect to the public's confidence in scientific leaders and institutions, the General Social Survey indicates that 41 percent of the public have a great deal of confidence and 49 percent have some confidence in scientific leaders, while confidence in other leaders and institutions has declined precipitously (Gauchat, 2011, 2012; National Science Board, 2016a). People's confidence in scientific leaders, as measured by the General Social Survey, also appears to vary with gender, age, and race/ethnicity, being somewhat lower among women, older Americans, and nonwhites (National Science Board, 2016a).

Individual and social factors beyond political ideology, such as race or ethnicity, income, religiosity, social capital, education, and knowledge, all can affect public trust in sources of information about science and of science itself, depending on the topic and the nature of the science being conveyed (Brewer and Ley, 2013; Gauchat, 2011, 2012; McCright et al., 2013b; Sturgis and Allum, 2004; Yearley, 2005). In addition, social identity—how people think of themselves in relation to various groups that matter to them—can affect how an individual thinks and feels about science (National Academies of Sciences, Engineering, and Medicine, 2016c), especially when that person has limited knowledge about an issue (Earle, 2010). Valuing scientific authority is positively related to level of education, and is also closely associated with trust in scientists and science more generally. This deference appears to be a long-term value on which people rely, especially when their knowledge of a topic is low (Brossard and Nisbet, 2007). People who defer to scientific authority have been shown to have higher levels of support for science or its applications, based in part on their trust in the experts, some research suggests (Brossard and Nisbet, 2007).

When information from science is at odds with one's political ideology, whether conservative or liberal, not only does acceptance of the information decline, as discussed earlier, but so, too, according to one experiment, does trust (Nisbet et al., 2015). The media, particularly partisan media, can affect people's trust in scientists, which in turn can affect their perceptions of science (Hmielowski et al., 2014; Nisbet et al., 2002). Preliminary research suggests that, at least in some circumstances, creating a less partisan atmosphere for scientists to engage with laypeople and apply logical reasoning to scientific evidence as part of drawing conclusions can help counteract motivated reasoning (Jamieson and Hardy, 2014).

A large literature shows that judgments about the warmth and competence of others are important to how people generally determine whether others have good intentions and the ability to act on them (e.g., Fiske et al., 2007). These factors are related to trust across a number of contexts, including risk communication, political communication, and employment settings (Chryssochoidis et al., 2009; Colquitt and Rodell, 2011; Fiske and Dupree, 2014; Peters et al., 1997). Another influence on trust is the audience's beliefs about the communicator's motives (Rabinovich and Morton, 2012; Chryssochoidis et al., 2009; Lang and Hallman, 2005). The perception of financial motives or self-interest, for example, is associated with lower trust in sources (Lang and Hallman, 2005). Other research has found that people resist what they perceive as an effort to persuade them (Byrne and Hart, 2009; Jacks and Devine, 2000).

When the source of information is an organization, the qualities of both the communicator and the organization affect trust. Qualities with a positive impact on trust include being perceived as having a good history of providing accurate information; being truthful; being concerned with public welfare; showing openness, concern, and care; being perceived as less likely to pursue self-interested motives; and being seen as knowledgeable (Chryssochoidis et al., 2009; National Research Council, 2012; Rabinovich and Morton, 2012). Individuals and organizations also may be more trusted when people believe the benefits of their research will be accessible to the general public (Critchley, 2008). Although the evidence that transparency increases trust is limited, a lack of transparency can increase distrust, as can omitting information about uncertainty from discussions of risk (Frewer et al., 2002; National Research Council, 2012). Perceptions of trust and different dimensions of fairness (e.g., the fairness of a process or its outcomes) appear to be closely related, but which perception precedes the other is unclear (Earle and Siegrist, 2008; McComas et al., 2007; McComas and Besley, 2011).

Some issues within the scientific community itself appear to have the potential to affect trust in science and scientists, although these effects have not been studied in great detail. Some of these issues stem from the complexities of translating the ways in which science is conducted; others from how scientists and others outside the scientific community, such as journalists, communicate findings; and still others from conflicts of interest, the deliberate misrepresentation of science, or failure to replicate findings (Ioannadis, 2005; Mnookin, 2012; National Science Foundation, 2015; Open Science Collaboration, 2015). The extent to which these issues actually do influence the perceptions of general lay audiences remains unclear.

Outcomes of Science Communication Affected by Trust and Credibility

As noted earlier, trust and credibility are important to science communication because they affect the degree of attention people pay to guidance from scientific experts, as well as whether they believe scientific findings or support science-related decisions (Bleich et al., 2007; Brossard and Nisbet, 2007; McCright et al., 2016; Rabinovich and Morton, 2012). Trust also affects attitudes toward science more generally. Differences in willingness to act on scientific information, for example, have been shown to be mediated by trust (Rabinovich and Morton, 2012). However, it is unclear whether attitudes toward an issue affect trust in the source of information on the issue or vice versa (National Research Council, 2012; Roduta Roberts et al., 2011). For an industry associated with science, preexisting levels of trust affect how both informative and positive news about that industry is perceived to be (Cvetkovich et al., 2002).

If people trust an institution to manage a communicated risk, they perceive the risk as smaller or the potential benefits as larger (Chryssochoidis et al., 2009). For example, trust in institutions has been shown to be a strong influence on support for nuclear power (Besley, 2010; Besley and McComas, 2015; Visschers and Siegrist, 2012; Whitfield et al., 2009).

Trusted friends and family may be important sources of motivation to take action on a science-related issue. For example, members of the public indicate that someone close to them, such as a spouse, child, or friend, would be the person most likely to convince them to take action to reduce climate change (Leiserowitz et al., 2013).

Science communication appears to be impacted more by the spread of distrust of science than by the building of trust (Slovic, 1999). Distrust is an assessment that someone lacks credibility and has a malevolent willingness to lie or deceive (Hon and Grunig, 1999). Distrust can arise from issues within the scientific community discussed earlier with respect to either the conduct or the communication of science, or it can be fostered by actions outside of the scientific community, such as misreporting or the deliberate spread of misinformation.

Distrust may be greatest in those science policy contexts in which individuals feel their values, identity, or interests are threatened, regardless of their ideology (Braman et al., 2012;

Kahan, 2012; McCright et al., 2013b; Nisbet, 2005, 2011). Overall, across issues and disciplines, trust as an appraisal of a communicator's motives, future intentions, integrity, and dependability, as well as confidence in the communicator's abilities, has proved to be important to people's perceptions of science and the way they interpret scientific information. In addition, aspects of the environment, including mass media, interact with trust in important ways.

However, research on the role of trust, credibility, and related elements in science communication has an important limitation that needs to be addressed: these concepts have been conceptualized and measured in a number of different ways. Moreover, an assumption of the literature related to trust is that people associate a message with a source and come to believe the message based on trust in that source. Yet some research shows that over time, people remember the content of the information they receive but fail to remember the source (e.g., Mares, 1996). And if people are exposed repeatedly to the same information, even from a fictional source, they may come to believe it is true (Shrum, 2007). Research is needed to understand the factors that influence people's trust in science and scientific information. As part of this research, it will be important to clarify the dimensions of trust and credibility and how they relate to one another. How does trust vary depending on the communicator, the goals for the communication (e.g., informational versus persuasive), and the communication context? How does trust change as science about an issue is communicated over time? What factors affect the trust and credibility of scientists and scientific understandings in science-related controversies? In such cases, for example, what are the effects on trust of science communicators being open about their own values and preferences?

APPLYING THE LESSONS OF LARGE-SCALE SCIENCE COMMUNICATION EFFORTS

Perhaps some of the most pertinent wisdom about effective science communication comes from experience with large-scale information campaigns, such as those for public health, undertaken to inform the public, shape opinions, and motivate behavior change. The challenges and successes of such campaigns offer a number of lessons, described below.

Exposure

Too little attention often is paid to providing sufficient exposure to information to reach enough of the target audiences to effect change. An exposure strategy involves defining how often, through what methods, and over what period of time a message should be disseminated and who the intended audiences are (Hornik, 2002). The plans for achieving the desired exposure will then constrain the shaping of messages, since the messages will need to suit the communication methods that the communicators can afford and control. To be effective, some types of messages—such as those that are addressing a problem that is not yet widely recognized or counterarguments to messages already received by the public—may require more exposure than others.

Timing

Research suggests that communication intended to educate may have more impact if provided before people form strong opinions about the topic. For example, people who have not yet heard of a technology, such as carbon capture and storage, can be influenced by short, relatively uninformative emotional messages. Once people's views have been shaped, however, it can be difficult to change those views by providing scientific information (Bruine de Bruin and Wong-Parodi, 2014; Lewandowsky et al., 2012). Observed "inoculation effects" in other areas of communication suggest that early communication about science, including equipping people with counterarguments that expose flaws in misinformation, also may "inoculate" the public from the spread of misinformation by those with a stake in misrepresenting the science (Cook, 2016). There is also support for encouraging healthy skepticism of sources of information as a way to reduce people's susceptibility to misinformation before they encounter it (Lewandowsky et al., 2012). Moreover, research on formal efforts to engage with the public suggests that, when possible, engagement should start long before an issue emerges in public debate (National Research Council, 2008). The case of gene editing, for example, highlights the need to consider public engagement efforts as early as possible in the evolution of a technology, well before it is developed and ready to be applied (Jasanoff et al., 2015). At the same time, however, early efforts to communicate science also have the potential to create a situation in which public debate becomes polarized and to foster activist publics (see, for example, Grunig et al., 1995). These factors can increase the complexity of the environment for communicating science, as discussed in Chapters 3 and 4. Thus, while early communication generally is better, more needs to be known about timing in light of the goals for communicating and the context.

Duration

Long-term and comprehensive approaches may be needed to achieve certain communication goals (Hornik, 2002). In the cases of smoking cessation, high blood pressure control, and prevention of HIV transmission, for example, communication efforts continued for months and even years, multiple agencies and constituencies engaged with the issue, the campaigns entailed routine media coverage, and so on. The underlying notion is that a strategy of repeated exposure to a message delivered in multiple formats by diverse actors via various platforms is effective for conveying a message of consensus to many segments of the public. Alternatives are available, such as attempting to shape news coverage (Wallack, 1993) or the content of entertainment shows (Singhal and Rogers, 2012). Adoption of these types of media strategies may achieve the needed exposure but will require ceding tight control of the message.

3
The Nature of Science-Related Public Controversies

Although the public has a generally positive attitude toward science and scientists, specific contentious issues with a science component often become controversial. As noted in Chapter 1, some of that public controversy stems from the fact that the science itself is inconclusive, and some from a disconnect between what science shows and either long-held common-sense perceptions or deeply held moral, ethical, or social values. Often the moral, ethical, or social implications of using science to develop or deploy a technology or to make a particular decision can be more contentious than the scientific findings themselves (Sarewitz, 2015). Public debate about the issues—among the scientific community, policy makers, and citizens—can help uncover common ground among people holding diverse sets of values. Although this is not always the case, clear information from science can enable people to make more informed choices. Healthy debate also can strengthen the science, challenging its claims and leading to a push for better forms of evidence.

When public controversies with a science component (science-related controversies) result from uncertainty—such as that which arises from either an inconclusive set of scientific findings or disagreements within the scientific community about how to interpret the results of science or how the results should be communicated—clear and accurate messages about the state of the science can be distorted and difficult to discern.[1] As discussed in Chapter 2, communicating science is almost always a complex task in part because scientific information and its implications are understood, perceived, and interpreted differently by different individuals, social groups, communities, and decision-making bodies. This phenomenon is not unique to science, but is important because it makes the process of communicating science difficult. In communicating about science-related controversies, such factors as conflicting values, competing economic and personal interests, and group or organizational loyalties can become central to a person's individual decision or to a decision on public policy.

Many parties—including corporations, advocacy and nongovernmental organizations, government agencies, and scientists themselves—typically are involved in debates about science-related controversies. The decisions made on these issues often involve corporate policies, laws and regulations, and international agreements. The high stakes of those decisions can pit the competing interests and political control of the various players against one another (Lupia, 2013; Nelkin, 1992; Nisbet, 2014). Organized interests other than science can play a large role in communicating about science related to contentious issues, and potentially influence people's judgments about science and the relevant scientific information.

To communicate science effectively under these conditions, an understanding of the factors discussed in Chapter 2 is insufficient. It is important to understand how and why science

[1]A lack of clarity about how to interpret scientific findings also can be due to problems within the scientific community that may include publication bias, misuse of statistics, issues of replication, stating conclusions beyond the data presented, and using causal language when not justified by the study design (see, for example, Gelman and Loken, 2013; Boutron et al., 2014; Ioannidis, 2005).

becomes part of public controversy and the forces that affect how people encounter, interpret, and use scientific information in these circumstances.

THE ORIGINS AND DYNAMICS OF SCIENCE-RELATED CONTROVERSIES

Controversies involving science exist, like all controversies, in particular historical, geographic, and social contexts. The political commitments, culture, history, and religion of an audience will affect its perceptions of science in general and of the scientific information related to an issue in particular. National cultures, for example, have varying effects on how people interpret and react to science (Bhattacharjee, 2010; Miller et al., 1997; Scheufele et al., 2009). This is why a scientific issue can be controversial in the United States but not in Europe, as is the case with climate change, or the reverse, as is the case with the introduction of genetically modified organisms (GMOs) in food. This phenomenon is not confined to nation-states. Organizations and civic institutions (i.e., nongovernmental groups that may include community organizations and professional, religious, political, consumer, activist, or charity organizations) involved in science-related controversies are not merely collections of individuals but have properties and dynamics of their own that, as noted in Chapter 2, affect how their members perceive information and make decisions.

The diverse nature and origins of science-related controversies defy simple classification and offer few neat comparisons. Much of what can be understood about these controversies comes from the historical record, case studies, ethnography, and other descriptive work. Still, despite their variety and their roots in historical and cultural circumstances, science-related controversies often share three features:

- Conflicts over the beliefs, values, and interests of individuals and organizations, rather than simply a need for scientific knowledge, are central to the debate.
- The public perceives uncertainty either in the science or its implications or as a result of communicators making different and sometimes contradictory statements in the public sphere.
- The voices of organized interests and influential individuals are amplified in public discourse, making it difficult for the state of the scientific evidence to become clearly known.

These three features present major challenges to communicating science effectively under conditions of controversy and are discussed in turn in the sections below. In each case, the discussion draws on examples from the research literature and points to implications both for communicators and directions for future research.

CONFLICTS OVER BELIEFS, VALUES, AND INTERESTS

Most public controversy, whether or not related to science, arises from the conflicting concerns of individuals and organizations. Controversy can be rooted in differing beliefs and values; personal, political, social, and economic interests; fears; and moral and ethical considerations—all of which are central to decisions and typically subject to public debate. When scientific evidence is relevant to a contentious issue, informing the public about it is critical. It is important to realize, however, that even if the science is clear, people may already understand it but still disagree agree with its implications. Some people, for instance, may recognize the benefit of a new technology but believe it is not worth its risks or judge its use to be ethically questionable.

Because a controversy can involve high-stakes commitments and interests, significant effort can be expended to rally the public. In a number of documented instances, organized interests outside of science have sought to protect their interests by promoting polarization on a controversy (alignment of members of the public along inflexible and diametrically opposed opinions) (e.g., Brownell and Warner, 2009; McCright, 2000; McCright, and Dunlap 2003; Michaels, 2006, 2008; Michaels and Monforton, 2005; Oreskes and Conway, 2011). Like other citizens, scientists and their organizations also have economic, professional, and personal interests that they may defend and promote, a fact that may influence the focus of their communication efforts.

Understanding the Role of Beliefs and Values of Individuals

As discussed in Chapter 2, when science and emerging technologies challenge people's beliefs and threaten deeply held values, their attitudes toward science and scientific informationcan be affected (Blank and Shaw, 2015; Lupia, 2013; McCright et al., 2016).[2] Across different science-related controversies, from climate change to GMOs to nanotechnology to genetic testing, people on opposite sides of the political spectrum who are demonstrably knowledgeable about the science may have opposite perceptions of or expressed support for the science (Cacciatore et al., 2012; Hart and Nisbet, 2012; Ho et al., 2008; Hornsey et al., 2016; Nisbet, 2014) and less trust in the scientists who conduct it (Pew Research Center, 2016b). The relationship between partisanship and perception or support also may be affected by people's patterns of media use (Cacciatore et al., 2012; Ho et al., 2008). In addition, information intended to persuade people to adopt particular practices or behaviors can have the opposite effect, and the effects of such messages can differ across groups (Asensio and Delmas, 2015; Byrne and Hart, 2009; Dietz, 2013a; Gromet et al., 2013; Nyhan et al., 2014). Gromet and colleagues (2013) found, for example, that the effectiveness of various frames for advocating energy efficiency varied depending on a person's political ideology (frames are discussed in Chapter 2).Examples from health (e.g., the human papilloma virus [HPV] vaccine and mammography) illustrate that an issue can be politicized when it becomes linked with political actors, partisan policies, or politically framed news about the issue, and that confidence in doctors and support for health policies and programs can be affected as a result (Fowler and Gollust, 2015).

In some science-related controversies, religious beliefs and values play a more central role than political ideology (National Research Council, 2008; Pew Research Center, 2015b). When the science concerns the origin of the human species or the universe, for example, people may feel that their religious views are being challenged, and their expressed views may reflect their faith consistent with their interpretation of the Bible rather than their understanding of science (National Research Council, 2008; see also for example, Berkman and Plutzer, 2010).

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[2]An extensive body of research addresses how to conceptualize values, beliefs, attitudes, and norms; how to measure them; and the interrelationships among them (Dietz, 2015; Oskamp and Schultz, 2005; Schultz et al., 2007; Steg and de Groot, 2012). Much of this literature has implications for understanding the effects of different approaches to science communication. For brevity, the phrase "values, beliefs, and interests" is used here to encompass the fuller set of social-psychological factors that influence understanding of science, acceptance of scientific messages, and the use of scientific information in decision making.

Citizens who choose their faith commitment over scientific accounts are not necessarily denying the science per se and may be well aware of the relevant scientific views (National Science Board, 2016b). In a 2012 survey, for example, half of respondents were asked to answer true or false to the statement, “Human beings, as we know them today, developed from earlier species of animals.” Among these respondents, 48 percent answered “true.” The other half of the respondents were asked to answer true or false to the statement, “According to the theory of evolution, human beings, as we know them today, developed from earlier species of animals.” Among these respondents, fully 74 percent answered “true” (National Science Board, 2014, 2016b; see also, for example, Berkman and Plutzer, 2010).

Various explanations have been offered for the polarization often surrounding science-related controversies. One such explanation, motivated reasoning, is discussed in Chapter 2. In this case, people tend not to adopt explanations that conflict with their long-held views or values. A related explanation is that cultural biases—specifically, preferences for equality versus authority and for individualism versus community—influence people’s risk perceptions and related beliefs (e.g., Kahan et al., 2009). According to this interpretation, people preserve their identities as members of social groups that adhere to certain cultural values to the extent that they will not adopt positions counter to those they believe are held by members of their group. It may be, however, that much of the American public has more moderate allegiances and views and thus is not subject to this effect of group values. Further, a number of studies suggest that individuals’ values predict their risk perceptions (Dietz et al., 2007; Slimak and Dietz, 2006; Whitfield et al., 2009). This research needs to be expanded and further integrated to determine its utility in predicting people’s responses to different approaches to communicating science.

Communicating Science in the Context of Competing Beliefs, Values, and Interests

Research has identified several strategies that can be used to mitigate the effects of competing beliefs, values, and interests on science communication. These strategies include tailoring messages from science for understanding and persuasion and engaging the public

Tailoring Messages from Science for Understanding and Persuasion

Tailoring scientific messages for different audiences is one approach to avoiding a direct challenge to strongly held beliefs while still offering accurate information. People tend to be more open-minded about information presented in a way that appears to be consistent with their values (Corner et al., 2012; Kahan et al., 2010; Lord et al., 1979; Maibach et al., 2010; McCright et al., 2016; Munro and Ditto, 1997). Using this approach can help build trust and credibility, but communicators of science need to avoid conflating scientific understandings with their own values (for further discussion of this issue, see Dietz [2013a]). They cannot assume that their information conveys a moral imperative or presume that their own values are universal.

Tailoring strategies have in some cases drawn on research in social marketing and audience segmentation (Bostrom et al., 2013) to persuade people to change their attitudes or perceptions or to take action for the public good based on established scientific evidence (e.g., improving vaccination rates for the sake of public health as well as of individual children). The practice of dividing a large potential audience into subgroups and tailoring messages differently for each subgroup is termed “audience segmentation.” Although most efforts to communicate science using these methods have taken place in the field of health communication (Slater, 1996), information about people's values and beliefs has in some cases been used to craft messages so as to motivate people to adapt to climate change or adopt views consistent with scientific consensus. However, research in this area is just emerging (Hine et al., 2016; Maibach et al., 2011; Moser, 2014). Other research has focused on tailoring messages to communicate information about the environment (e.g., Spartz et al., 2015a; Witzling et al., 2016).

Research on audience segmentation methods needs to be replicated and extended for researchers to understand how much of an effect science communication can have, for whom, and in what contexts. A related issue is how tailored messages designed to persuade people to adopt scientifically supported positions might affect their perceptions of scientists and scientific information.

Engaging the Public

One approach to communication in the context of science-related controversy, discussed in Chapter 2, is to engage the public in formal processes for participating in decisions on such issues. Public participation is a formal process for engaging the public that is often adopted by elected officials, government agencies, and other public- or private-sector organizations to increase the public's involvement in assessment, planning, decision making, management, monitoring, and evaluation (National Research Council, 2008). Research on public participation has examined the conditions and practices that can make it a successful approach for adjudicating differing views. Research on this topic varies in scope, with some areas studied far better than others. Studies of the National Academies have examined procedures for public participation in the assessment of risk and in decision making related to technology and the environment for more than two decades (National Research Council, 1996, 2008). In a review of the literature covering roughly 1,000 studies related to environmental issues, a National Academies report offers principles of effective public engagement and concludes:

> When done well, public participation improves the quality and legitimacy of a decision and builds the capacity of all involved to engage in the policy process. It can lead to better results in terms of environmental quality and other social objectives. It also can enhance trust and understanding among parties. Done well, processes that foster trust and that address the concerns of affected stakeholders can be effective in diminishing controversy around science in the public sphere. (National Research Council, 2012, p. 226)

To be most effective, public engagement needs to be undertaken as early as possible in a public debate, and those with a stake in the issue need to be engaged over many rounds of back-and-forth communication with each other. Often the first step is for scientists and interested and affected parties to work together to identify topics of concern and assess the degree to which research can clarify those concerns. Repeated deliberation over time builds trust among diverse participants—an approach that is much more successful than inviting participation after a conflict has emerged and intensified. In some such cases, participation processes have reestablished trust, but communication remains more difficult than when public participation is initiated early on. Other potential pitfalls in the public participation approach include perceived political manipulation of the process, a lack of fairness in the relative amount of attention given to different participants, and stakeholders who work only toward trivial or undesirable results

(National Research Council, 2008). Further, some claims may be perceived as majority views simply because they are made loudly and frequently (Binder et al., 2011). This effect has been shown to influence policy decisions (Binder et al., 2012), and science communicators may need to take steps to clarify or counter it. The gender mix of participants also can influence deliberation, although careful design of the process can counter these effects (Karpowitz et al., 2012; Mendelberg et al., 2014). In general, for public engagement to achieve its potential, care must be taken to design a process that is attentive to the character of the issues at hand and that takes into account the strengths and weaknesses of individual thinking and group interactions (for further discussion of these factors, see National Research Council [2008]; Lupia [2002]; Lupia et al. [2012]).

Systematic reviews of research on public participation focus mainly on environmental assessment and decision making. Additional synthesis and research are needed to identify the elements of structures and processes for communicating science effectively in public forums across a range of social issues (e.g., biomedical research, health policy, gene editing, education policy) and types of controversies. Further, given that best practices in public engagement suggest that it take place early on, research is needed to examine to what extent and in what ways communicating science in formal public participation processes can be effective once an issue has become contentious and the science related to the issue controversial.

PERCEPTIONS OF UNCERTAINTY

As noted in Chapter 1, some science-related controversies arise because the science around a topic is or is perceived by many to be uncertain or unclear. This uncertainty can stem either from uncertainty about the science itself, when no scientific consensus exists, or from people's mistaken impressions about the degree of certainty within the scientific community (see Chapter 2 for a discussion of sources of scientific uncertainty). Motivated reasoning (also discussed in Chapter 2), comes into play frequently when people are exposed to ambiguous statements and then interpret the ambiguity to support their own long-held views (e.g., Budescu et al., 2009, 2014; Dieckmann et al., in press).

Uncertainty about the Science Itself

As noted earlier, some controversies may reflect at least in part disagreement within the scientific community about where the weight of evidence lies. Among these controversies are disputes about the causes and impacts of obesity, the relative merits of technologies for responding to climate change (such as carbon capture and storage and solar radiation management), the social and health impacts of vaping, and the academic consequences of introducing more market-like policies (such as vouchers or charter schools) in education.

Controversies involving scientific uncertainty also can hinge on whether the science is adequate to determine cause and effect or to predict future risks or benefits. Examples of these kinds of controversy are disputes over the connection between diet and chronic disease; the debate over the risk of radiation exposure from cell phones; and disagreements over whether the benefits of electricity production from nuclear power outweigh the risks (Visschers and Siegrist, 2013). Many such disagreements remain within the scientific community or at most spread to a broader but still relatively small and attentive audience of interest groups, specialists, or policy networks. In other cases, however, particularly those involving issues with wide societal implications or issues, such as food and nutrition, that affect personal interests, more of the public begins to encounter and pay attention to the relevant science and invoke it when participating in public debate. Examples include controversies involving energy and environmental policy, stem cell therapy, and gene editing technology. In such cases, a debate once confined to scientists and a few onlookers comes to include more diverse actors and influencers, such as public officials, commercial interests, the media, social media commentators, celebrities, and various organized interest groups. These participants often state strong opinions about whether science is adequately equipped to assess benefits and risks and make forecasts with respect to an issue.

Uncertainty within science also can occur because a field of study is relatively new, and much remains unknown. Emerging evidence can vary in its quality, or it can be limited by the methods, samples, or contexts involved in its collection or by the amount of evidence that has accumulated and been replicated. More often than not, in the absence of clear consensus, the public and scientists themselves must determine what to believe and what choices to make given the state of the evidence as they understand and interpret it. For example, scientific disagreements about the potential of particular substances to cause cancer can fuel public controversy over exposure to those possible carcinogens (Löfstedt, 2003).

Another form of uncertainty-driven controversy can emerge from disagreement about the ethics, uses, or estimated impacts of an emerging technology when certain consequences must be forecast, given the inherent lack of certainty that forecasting entails. Similarly, uncertainty can result when scientists are asked to translate general knowledge about a subject into recommendations for a particular community or population. Scientists who work from a widely accepted and rich knowledge base about a toxic substance, for example, may nonetheless lack evidence about the risks that substance poses when a particular amount of it has contaminated groundwater in a specific community for which no prior data exist (Rosa, 1998; Rosa et al., 2013). In such cases, the extrapolation required almost inevitably increases uncertainty and necessitates careful assessment; it also means that members of the local public may have knowledge that, while not scientific, can be essential to applying scientific knowledge accurately to the local context (Dietz, 2013b; Wynne, 1989). It is interesting to note that in cases of prolonged controversy, members of the public can develop considerable expertise in the relevant science (e.g., Brown, 1992; Epstein, 1995; Kaplan, 2000; Kinchy et al., 2014).

Controversies that invoke or exaggerate scientific uncertainty often focus on risk or risk–benefit assessments. Risk decisions by their very nature center on uncertainty. How likely is an event to occur? Are the benefits involved likely to outweigh the harms? Many of the most contentious policy decisions concern managing environmental and human health risks.

Risk has been formally defined as the product of the likelihood and severity of future harm (Brewer et al., 2007; Kaplan and Garrick, 1981). People, though, use multiple means of understanding risk, some simple and some sophisticated, and all influenced by emotions and complex considerations such as familiarity, uncertainty, dread, catastrophic potential, controllability, equity, and risk to future generations (Finucane et al., 2000; Keller et al., 2006; Slovic, 1987, 2000; Slovic et al., 2004). Although individuals make judgments about risk, there are larger societal risks related to science and technology that emerge from and benefit from broader societal debate (National Research Council, 1996). Gender and race also play a role in how people perceive risk (e.g., environmental health risks), for reasons that are not entirely clear (Flynn et al., 1994; Satterfield et al., 2004). Controversies over risk often trigger competitions in which each group with a stake in the issue tries to persuade the public to share its perception of a particular risk. Some ways of communicating risk in the context of controversy have been studied (Fischhoff, 1995). Indeed, much of the early work in the field of risk perception and communication addressed controversial environmental risks, including the siting of nuclear power plants and waste facilities, chemical hazards, and other technological risks (Slovic, 2016).

Many of the strategies studied have focused on communicating and managing risk under conditions of uncertainty (Fischhoff, 2012; Fischhoff and Davis, 2014; Renn, 2008; Rosa et al., 2013), in part because uncertainty is inherent in scientific inquiry and because it is this uncertainty that is often exploited during controversies. As with other aspects of the science of science communication, however, much of the advice available to practitioners regarding risk communication under conditions of uncertainty or in the context of a crisis or controversy is based on case studies, personal experience, and face-valid principles lacking rigorous empirical testing. In addition, the available empirical research typically is limited by its focus on specific risk controversies or crises, frequently within the bounds of a particular geography or period of time, rather than on cross-cutting or comparative issues. Moreover, research on presenting uncertainty often is based on hypothetical scenarios (see, for example, LeClerc and Joslyn, 2012). More work is needed both to consolidate and to validate what is known in this area, and research is needed on the most effective ways to present risks of varying degrees of certainty.

Misunderstanding and Misrepresentation of Scientific Uncertainty

In some instances, the relevant science is well established and agreed upon by the majority of the scientific community, but some uncertainty still exists. In such cases, the level of scientific agreement can be misunderstood or misrepresented in public discourse. Examples include current understanding from science about the human contribution to climate change, the health benefits of vaccines, and the validity of evolution. Some misunderstanding can arise from poor communication or from any of the challenges to understanding scientific information discussed in Chapter 2. The way the media portray the weight of evidence also can misrepresent the degree of scientific consensus on an issue, as when opposing views are presented equally (i.e., “false balance reporting”) regardless of the prevalence of a view or the extent to which it is supported by evidence (Bennett, 2016; Dixon and Clarke, 2013).

Analyses of past and ongoing science-related controversies indicate that organizations sometimes create doubt about what science says so as to protect their economic interests or ideological preferences (Brownell and Warner, 2009; McCright, 2000; McCright and Dunlap, 2003, 2010; Michaels, 2006, 2008; Michaels and Monforton, 2005; Oreskes and Conway, 2011). Both questioning the validity of research and exaggerating the extent of disagreement among scientists can create uncertainty and thus impede people’s understanding of what the scientific community is communicating (Brownell and Warner, 2009; Freudenburg et al., 2008). This strategy was used by the tobacco industry to obscure the harmful effects of smoking from the public, but interested parties have used similar approaches to exaggerate supposed uncertainty about climate change and the food industry’s contributions to obesity (Brownell and Warner, 2009; Dunlap and McCright, 2010). Organizations and individuals whose interests are served by sowing doubt about findings from science may feed particular media outlets and policy makers who often are sequestered from other messages, leading to media “echo chambers” in which only their inaccurate assessments of uncertainty are heard (Dunlap and McCright, 2010).

Communicating Uncertainty and Consensus Amid Controversy

Correcting misperceptions of scientific consensus can be a first step toward influencing attitudes, on such issues as climate change and vaccination, that in turn shape decisions. Although it is true, as described previously, that many people resist information that appears to threaten their beliefs, it is also true that an accurate sense of scientific consensus can have an impact on people's policy preferences. When people learn that most scientists agree about climate change, for example, they are more likely to believe that global warming is occurring and to express support for policies aimed at mitigating it (Ding et al., 2011).

In combating inaccurate claims of uncertainty, it may be useful to communicate repeatedly the extent of expert agreement on the science concerning a contentious issue. Such repeated communications can occur in many places, involve diverse people, and take various forms—conversations, use of social media, presentations, advertising, communication campaigns, and media interviews (see van der Linden et al., 2015). As discussed earlier, however, communicating scientific consensus may also deepen divisions in views about science, such as when the communications involve perceived attacks on values or the groups that hold them (Kahan, 2015). More research is needed to determine ways of communicating expert consensus that can help achieve understanding.

Other research suggests that there can be benefits to being explicit about the uncertainty involved in scientific understanding, being fully transparent about how scientific conclusions are reached and how uncertainty is reduced over time (Druckman, 2015; Jamieson and Hardy, 2014). Explaining how conclusions have been reached may build credibility, as well as create greater public interest in an unfolding story or mystery about scientific investigation and discovery (Druckman, 2015). More research is needed on the efficacy of consensus messaging, ways of talking about uncertainty, and the conditions under which these communications are likely to be effective.

In some domains, including sexually transmitted infections (Downs et al., 2004), vaccination (Downs et al., 2008), climate change (McCuin et al., 2014), and environmental hazards (Lazrus et al., 2016; Morss et al., 2015), effective communication has been developed through research with the intended audiences aimed at understanding how to address their concerns and misunderstandings. Although people tend to retain their common-sense mental models of how the world works (Niebert and Gropengießer, 2014; Vosniadou and Brewer, 1992), controlled laboratory experiments show that people can revise their thinking in response to information that explains underlying causal processes (Ranney et al., 2012). This approach has been used to improve understanding of how people think and make decisions about a variety of contentious science issues. More work is needed, however, to determine how such approaches to understanding audiences could be implemented on a large scale.

AMPLIFIED VOICES OF ORGANIZED INTERESTS AND INFLUENTIAL INDIVIDUALS

Science communication may take into account the beliefs and values of varied audiences and communicate well about the weight of evidence but still go unheard in discussions about controversies. High stakes, conflicting interests, uncertainty, and concerns about risk and the consequences can expand the number and diversity of people who attempt to communicate about science, as well as the number of parties who use the science. Public officials may call on science experts to help craft solutions to policy issues of concern to the public. Lawyers and courts may seek evidence pertinent to important judicial cases that garner publicity. Members of the media may look to noteworthy findings from science in an effort to craft stories that will speak to the needs or interests of their audiences. And those with stakes in the outcome on either side of a debate (partisan politicians, corporations, other mobilized advocacy or interest groups) may use science that supports their claims.

Because science-related controversies often involve or invoke policy responses, they raise the likelihood that the key actors will be organized interests (e.g., corporations, partisans, organized religion, advocacy groups, government agencies, universities) subject to various pressures, incentives, and institutional constraints. These elements may be as important to audiences—or more so—than an accurate understanding of the relevant science. In the context of controversies, scientists and the enterprise of science may be seen (sometimes correctly, sometimes not) as interested parties with their own motivations or organizational interests at stake.

Scientists are not immune from personal, academic, and societal pressures. Although it can be difficult for the scientific enterprise to self-correct, science as an institution possesses norms and practices that restrain scientists and offer means for policing and sanctioning those who violate its standards. In contrast, as discussed earlier, those who are not bound by scientific norms have at times intentionally mischaracterized scientific information to serve their financial or political interests (Dunlap and Jacques, 2013; Farrell, 2016; McCright, 2000; McCright and Dunlap, 2003, 2010; Michaels, 2006, 2008; Michaels and Monforton, 2005; Oreskes and Conway, 2011).

Framing the Issues Involving Science

Almost all participants in a controversy will seek to frame their issues to their advantage (for a detailed discussion of framing, see Chapter 2). Such framing influences the amount of attention an issue receives, which arguments or considerations are seen as legitimate, and which individuals and groups have standing to express their opinion or participate in decisions (Nisbet and Huge, 2006). As attention to an issue grows and conflict increases, new participants may attempt to bring different frames to bear in an attempt to recast the conflict in ways that serve their goals. Food and environmental activists, for example, have promoted the term "frankenfood" to suggest unnatural dangers associated with food biotechnology, thus framing the issue in terms of unknown risks and unintended consequences rather than the industry-promoted focus on reducing world hunger. Likewise, climate change activists have adopted the term "big oil," a headline-friendly phrase that triggers associations with corporate accountability and wrongdoing. The echo of the phrase "big tobacco" also associates the issue of climate change with an earlier generation's discovery of the dangers of smoking. Once a frame has influenced people's views, those views can be difficult to change. One study, for example, found that people who had never heard of carbon capture and storage could be influenced by uninformative arguments either for or against the technology, and that those manipulated feelings persisted even after these people had read carefully balanced communications designed to educate them (Bruine de Bruin and Wong-Parodi, 2014). More needs to be known about how audiences make sense of the competing frames they encounter from multiple sources.

Debunking Misinformation

Many science communicators, especially those who are scientists, typically feel an urgent need to correct information that is inconsistent with the weight of scientific evidence. As noted above, however, doing so actually is difficult under most circumstances (Cook and Lewandowsky, 2011; Lewandowsky et al., 2012). In addition, well-intentioned, intuitive efforts to debunk misinformation can have the unintended effect of reinforcing false beliefs, especially among the more educated (Cook and Lewandowsky, 2011; Nyhan et al., 2013, 2014; Skurnik et al., 2005). Correcting false beliefs also is more difficult when the incorrect information is consistent with how people already think about the information or issue. In fact, when people are challenged in their beliefs, they may react by dismissing the credibility of the messengers who provide the corrections (Lewandowsky et al., 2012).

In addition, repetition of false information, such as that which may come from faulty science not generally accepted by the scientific community (i.e., “junk science”), can reinforce the belief in that information even if followed by correction. And providing too much or overly complex information to correct a simply worded myth is likely to be ineffective. It is possible that debunking efforts may be more effective with the undecided majority of people than with the firmly entrenched minority. More study is needed to determine for whom and under what conditions current understandings about debunking may hold.

One approach to avoiding the risks of debunking is to focus on messengers instead of their messages. In some cases, inducing skepticism about or distrust of a communication can help combat the effects of misinformation (Bolsen and Druckman, 2015). One such strategy, alluded to in Chapter 2, involves “prebunking” or “inoculating” audiences against the intentional efforts of individuals or organizations to mislead the public. This can be done by warning people that they may be exposed to misinformation and explaining why misleading information is being promoted (Bolsen and Druckman, 2015; Cook, 2016; Lewandowsky et al., 2012), but more needs to be known about when and for whom this strategy can be effective.

When the source of misinformation is within the science community itself, even well-publicized retractions and corrections can have little effect (Mnookin, 2012). One study suggests three factors that increase the effectiveness of retractions: warnings at the time of initial exposure to the misinformation; repetition of retractions; and corrections that tell coherent, plausible alternative stories, explaining the source and motivation behind the misinformation (Lewandowsky et al., 2012).

As described in Chapter 2, the successes and failures of large public health campaigns offer a number of lessons. They suggest that gaining sufficient exposure, engaging with audiences early on, and then applying a variety of communication approaches over an extended period of time can help ensure that the perspectives of science are heard among the amplified voices that may characterize science-related controversies.

Working with Opinion Leaders to Inform and Persuade

Another way to bring accurate scientific information to the public is to work with opinion leaders—politicians, business leaders, community figures, journalists, celebrities, and others with a proven capacity to influence people’s views. Marketers, advertisers, and campaign strategists have targeted opinion leaders as effective promoters of positions, candidates, or products for decades. Until recently, however, opinion leaders have received little attention among researchers and practitioners in science communication. Yet research from these fields that have targeted opinion leaders suggests effective approaches that could be adopted for enlisting these leaders to help in effective science communication (Nisbet and Kotcher, 2009). At the same time, the engagement of opinion leaders may carry some risk. Such leaders come from the realms of politics, media, and celebrity, all of which have less public credibility in general relative to scientists. Whether practices associated with industry and politicians could damage the credibility of scientists is unknown (Lang and Hallman, 2005; Pew Research Center, 2015a).

Opinion leaders who are not prominent individuals but are nonetheless influential in their social circles can be identified informally through observation or surveys (Frank et al., 2012; Nisbet and Kotcher, 2009; Roser-Renouf et al., 2014). Research suggests this to be a promising way to help achieve the goals of science communication. The actions people report being willing to take to reduce climate change, for example, are most likely to be influenced by a person close to them, such as a significant other or close friend (Leiserowitz et al., 2013). Similarly, at least one-third of Americans would sign a petition, attend a meeting, or support a candidate who shared their views on climate change if asked by someone they "like and respect" (Leiserowitz et al., 2014). Examples outside of science communication also indicate that community members can play important roles as opinion leaders (Dalrymple et al., 2013; Howell et al., 2014).

Of course, scientists themselves can serve as trusted opinion leaders, sparking conversations and the sharing of information among coworkers, friends, neighbors, and acquaintances both in their everyday interactions and in social media. One study found that, beyond the social influence aspects of conversation, discussing science with trusted acquaintances led to a richer understanding of climate change and greater use of this knowledge in making decisions or offering an opinion (Eveland and Cooper, 2013). Likewise, a survey that tracked the discussion patterns of Americans for 2 years found that people's attention to science-related news coverage was associated with having more frequent conversations about science, which in turn was associated with an increase in overall concern about climate change. This heightened concern was related to a subsequent increase in attention to news coverage of science, as well as to more frequent science-related conversations and even greater levels of concern about climate change over time (Binder, 2010).

Further research is needed to understand how different types of opinion leaders may affect people's understanding of and tendency to use information from science in their decision making.

4
Communicating Science in a Complex, Competitive Communication Environment

Recent years have seen widespread and dramatic changes in the way people seek or encounter information about science and the issues of concern to them. These changes present additional challenges to communicators of science regardless of whether the science is involved in public controversy. Gone are the days when citizens obtained much of their information from relatively few radio and television networks, magazines, and newspapers. Today, people may encounter scientific information from a wide variety of media operations, as well as blogs, social media feeds, podcasts, YouTube channels, and a host of other sources that did not exist 20 years ago. At the same time, some of the ways citizens have in the past received high-quality information about science and social issues are fading away. Traditional news sources, for example, face severe economic challenges. Newspaper circulation continues to decline with each passing year (Pew Research Center, 2016a), reducing the number of professional journalists writing news. American newspapers in 2014 had some 33,000 full-time newsroom employees—20,000 fewer than they did in 1994 (Pew Research Center, 2016a). This chapter examines in turn trends in the communication of science news, how journalistic decisions affect the coverage of and audiences for science, and emerging research on use of the Internet as a source of science news.

TRENDS IN THE COMMUNICATION OF SCIENCE NEWS

While the ongoing changes summarized above affect the media system more broadly, they have had particularly strong impacts on how science is communicated in the media. Three trends are particular noteworthy (Scheufele, 2013).

First, as noted above, people have shifted away from traditional media (especially newspapers and television) and toward online-supplemented or online-only news for scientific information. This trend is especially pronounced among younger and scientifically literate audiences (Su et al., 2015). In 2014, 47 percent of Americans reported that the Internet was their primary source of news and information about science and technology, up from just 9 percent in 2001. In comparison, 28 percent said television was their primary source of such information, down from 32 percent in 2012. As for other sources, 7 percent named print magazines as their top source, 6 percent print newspapers, and 3 percent radio (National Science Board, 2016a). Younger, higher-earning, and better-educated Americans were more likely to say they receive most of their information about science and technology by way of the Internet, online newspapers, online magazines, or similar sources. Older and less-educated Americans were more likely to continue to rely on television news and print sources (National Science Board, 2016a).

Of the roughly half of Americans who said they rely primarily on the Internet for information about science and technology, a little more than a third said they use a search engine such as Google; a combined 45 percent said they use primarily online newspapers (23 percent), online magazines (15 percent), or other online news sites (7 percent). Just 8 percent of Internet information seekers—or 3 percent of all Americans—said they rely on a science-focused site as their primary source of information about science and technology (National Science Board, 2016a). Similarly, a 2015 poll conducted by the Associated Press and other organizations found that more than half of American adults asked about their top source of information about science and technology identified search engines, just over 40 percent cited Facebook, and more than 30 percent conversations with friends and family as their top three sources of information about science and technology (Brossard, 2016). Several tools available through Google enable keyword searches and queries that provide a potentially useful source of data about the public's interest in science generally and in specific topics over time, including how public interests compare with news coverage. However, such tools are difficult to apply across countries and do not account for the interests of those without access to the Internet (Baram-Tsabari and Segev, 2009; Segev and Baram-Tsabari, 2010).

Online information environments—especially since the advent of smartphones and other mobile devices—have the potential to deliver more scientific information more quickly than ever before and make their users largely independent of physical repositories, such as libraries (Scheufele and Nisbet, 2012). At the same time, web 2.0 environments (websites that encourage and depend upon content created by their visitors) have made it possible for users to debate news among themselves and to comment on, share, and repurpose information (to some degree) independently of commercial media outlets.

The second noteworthy trend is that "news holes"—the number of column inches devoted to news in print or the time available for news on television—have been shrinking. For science coverage, this trend has been particularly dramatic. In 1989, 95 U.S. newspapers had weekly science sections; by 2012, only 19 still did (Morrison, 2013).

As might be expected, this decline is an important driver of the third key trend: the shrinking number of science journalists employed full-time at news outlets. Professional journalists with knowledge of the science about which they are reporting often have a different but important role to play in people's understanding of science,[1] but represent a smaller proportion of the science information available to media consumers even as the scope and size of that information have increased (Scheufele, 2013).

Although the traditional infrastructure for science news is declining, communicators have new ways to participate in public debates about science, and more scientists than ever are now speaking directly to the public via blogs, podcasts, YouTube videos, and the like. This widening of channels for scientific information has allowed more science communicators to try to reach the public. But it also means there are more actors in the media landscape who may, either intentionally or unintentionally, provide inaccurate science information. So while today's science media landscape is likely larger than the declining mass media/newspaper-delivery system of the past, that expanding landscape does not offer clear mechanisms for filtering out false, sensational, and misleading information. More than ever before, citizens are left to their own devices as they struggle to determine whom to trust and what to believe about science-related controversies.

This is the new, and not entirely understood, media environment with which science communicators must cope.

[1] For further discussion of journalistic goals and norms versus those of science, see Nelkin (1996) and Dunwoody (2014).

HOW JOURNALISTIC DECISIONS AFFECT SCIENCE COVERAGE AND AUDIENCES

Despite the growing impact of new media, much of the scientific information Americans receive through media still originates from traditional journalism, including information transmitted via links on social media. Therefore, science communicators need to understand the tools used by journalists to shape scientific information, especially that related to contentious societal issues.

How Science Is Covered in Mainstream News

A number of factors, closely related to framing (see Chapter 2), influence journalists' decisions about how much attention contentious issues and the related science receive (agenda building) and how those issues and the science are defined or portrayed (for an overview, see Scheufele, 1999). Among the most important of these factors are the tactics journalists can use to present new information. Journalists covering complex policy debates tend to rely on a few standardized plots and news formats (Bennett, 2016). When a new issue, such as food biotechnology or stem cell research, taps familiar themes from previous political conflicts or evokes story lines familiar from popular culture and history, journalists cast the new issue's actors and events to fit these well-known story lines.

Science-related policy debates become most newsworthy, for example, when they involve clear conflict leading to a promise of resolution, such as the passage of legislation, the veto of a bill, or an international climate change summit—a scenario that Cook (1996) describes as "conflict with movement." When policy making appears to be stuck in a quagmire, with no movement on legislation or no political decision on the horizon, news coverage of a complex science-related issue cannot build anticipation for a resolution. As a result, news reporting on such issues is less frequent and less successful in garnering attention (Nisbet and Huge, 2006, 2007).

Similarly, once a conflict appears to have been resolved, even if only partially or temporarily, the inherent drama of the issue is lost for many journalists. Absent a new scientific discovery or the need for a political decision on the horizon, journalists need a drama on which to focus (McComas and Shanahan, 1999). This need for effective narrative explains why the perceived political relevance of a science-related issue is critically important to how much news coverage it receives. On most science-related issues, journalists provide a relatively steady amount of coverage as they follow the release of each new study on an issue. But when an issue such as biotechnology or climate change receives attention because of a congressional debate or White House statement, that issue becomes more relevant to political conflict. The issue then gains the attention of political journalists, general assignment reporters, and opinion writers who do not regularly communicate about science. These journalists outnumber science writers, and political conflict receives more coverage than science. Thus when an issue becomes defined as politically relevant, the potential for it to receive a high volume of coverage increases (Kepplinger, 1992, 1995; Nisbet and Huge, 2006, 2007).

Of course, experienced news sources formulate their message strategies to accent familiar themes (Nisbet and Huge, 2006, 2007; Nisbet et al., 2003). Hence, journalists often evoke images of ethical quandaries or extremes of risk or benefit to meet the need for dramatic structure. Meanwhile, political reporters, who tend to frame almost all aspects of public life as if they were simply a matter of political competition (Cappella and Jamieson, 1997; Patterson, 1994), impose their own interpretations on science stories. Their framing of an issue emphasizes who is ahead or behind and the episodic day-to-day tactics employed by strategic actors to gain an advantage. These frames generate drama, first by focusing on conflict, with an expectation of winners and losers, and second by personalizing the news through a focus on individual battles between specific actors. This framing spurs political journalists to treat opposing claims as if they were equal—leaving the public with the impression, for example, that scientific debate about climate change has equal numbers of advocates on both sides (a phenomenon known as "false balance"; see Chapter 3) (Bennett, 2016; Nisbet et al., 2003).

It is important to understand and track over time how science is covered in the media because, as discussed in the next section, coverage can affect audience perceptions of the issues that should be of concern to them personally and should receive priority in public policy agendas. Moreover, media coverage can be expected to affect how science communication from other sources is interpreted, a contextual factor that needs to be considered in research on science communication.

How Coverage of Science Affects Public Perceptions

By giving attention to some issues over others, the media influence what the public perceives as most pressing and important (Iyengar and Kinder, 1987; McCombs, 2004). Consistent with this hypothesis, studies tracking news attention and public perceptions typically find that a rise in overall news attention to an issue precedes a rise in public concern (McCombs, 2004; Rogers et al., 1991). In addition, laboratory experiments indicate that when subjects are repeatedly shown newscasts over a week, the top issues featured in those newscasts emerge as among the subjects' primary national concerns (see Iyengar and McGrady, 2007, for discussion). When individuals are asked to describe the issues that are of most concern to them or are the most important facing the country, or to reflect on how worried they are about a risk, their responses are most likely to reflect the extent of their media exposure to the issues, as well as whether the issues affect them directly (Kim et al., 2002; Scheufele, 2000). Recent experience with Ebola and swine flu reflect these effects (Pew Research Center, 2009b, 2014). This is why the narratives that shape science coverage in the media are important to science communication. The inappropriate fears over Ebola and swine flu fanned by the media illustrate how the media's narrative frames can make it difficult to get accurate science onto the public agenda.

The amount of coverage received by issues or events in the news also often serves as the criterion by which the public evaluates the performance and credibility of a political leader, government agency, scientific organization, or corporation (Iyengar and Kinder, 1987; Nisbet and Feldman, 2011). Political leaders and organizations recognize and anticipate these effects. As a result, when an issue or event rises on the overall news agenda and thereby becomes an object of public concern, political actors are likely to take some form of action to address it, even if only symbolically. This action may be taken with little to no expert advice on the subject given that, as discussed in Chapter 3, actions on contentious issues in society often are driven by values, beliefs, and other considerations.

Thus research on the agenda-setting effect of the media has repeatedly provided evidence that the issues portrayed in the media shape the issue priorities of the public. The effects of such agenda setting can be both positive and negative. In the case of Ebola, for example, news coverage that drove the issue to the top of the public's agenda led policy makers to call for restricting air travel from Africa and quarantining all medical personnel returning from the area, both of which ran counter to the advice of the Centers for Disease Control and Prevention. At the same time, increased coverage of the epidemic led policy makers to make a substantial investment in controlling it. The effect of media coverage on the priorities of policy-making institutions in general, however, is less well understood than its effect on the priorities of the public. Research in this area has yielded mixed results (Kingdon, 1995), and whether the media drive policy or the reverse is unclear (Wolfe et al., 2013).

More is known about journalistic decisions and their effects on audiences in traditional news outlets than in new media. An important question for research is how these processes operate and affect audiences for scientific information in rapidly changing online environments. As their audiences have decreased and turned to online media as primary sources for scientific information, traditional media organizations have devoted less space and time to science (National Science Board, 2016a; Su et al., 2015). There is as yet no clearly viable business model that can sustain traditional journalistic organizations (and thus their practices) in an online environment.

On the one hand, online channels have made information more easily and more widely accessible. On the other hand, new information-filtering tools that people can use to block information with which they disagree have made it easier than ever to hear and see only news that accords with one's beliefs (Scheufele and Nisbet, 2012). Thus the online information environment has been called an "echo chamber" (Sunstein, 2009) and a "filter bubble" (Pariser, 2012). As noted previously, all people filter information through preexisting beliefs. At the dawn of web 2.0, some were optimistic that an Internet full of user-controlled web experiences and user-generated content would become a platform for informative and helpful dialogue about science. This view has since been tempered by the emergence of filter bubbles, abundant uncivil online comments on science news stories, and the detrimental effects of those comments on interpretations of these stories (Anderson et al., 2014; Brossard and Scheufele, 2013). In this noisy information landscape, scientists have difficulty finding responsible ways to ensure that the public has access to clear and credible evidence.

Opportunities for Communicating Science: Social Media, Social Networks, and Blogs

Social Media

Social media offer expanded opportunities for science communication and the exchange of ideas, but they differ in important ways from traditional media and even online versions of traditional media outlets. Social media offer platforms with user-generated content and interactions, and their information is tailored and targeted toward specific individual users (Cacciatore et al., 2016). The platforms vary in the extent to which they enable people to have a social presence, and people vary in how much information they disclose about themselves (Brossard, 2012). Generally, however, like-minded individuals can find one another and interact through social media. They can form social networks and communities that share and spread information with great speed. (This effect is enhanced when the information flows through particularly influential individuals within a network [Brossard, 2012].)

The popularity of a given platform or site and the demographic characteristics of its users often shift rapidly (Kümpel et al., 2015). As of this writing (in 2016), young adults, for example, are increasingly using SnapChat and Instagram, while their use of Facebook is decreasing

(Brossard, 2016). Partly as a result of this highly dynamic environment, the effects of a particular platform are difficult to disentangle from other influences that may explain an individual's attitude, preference, or behavior. These realities pose challenges for researchers seeking to understand the impact of social media on science communication. A recent review of research conducted between 2004 and 2014 on news sharing in social media (Kümpel et al., 2015) identified a number of important tasks for researchers, including the need to keep pace with changes in the media landscape, the need to devise more comprehensive models of news and social media, and the need to derive more information about news-sharing networks.

Scientists' use of social media An emerging body of research examines scientists' own use of social media. Some researchers have found that scientists' use of Twitter can amplify their scientific impact, with tweeted work being cited by other scholars more frequently than other work (Eysenbach, and Köhler, 2002; Liang et al., 2014). Other research from the biomedical and health domains contradicts these findings, however, with articles shared on Twitter and other social media being no more likely than nonshared articles to be cited by other researchers or downloaded (Haustein et al., 2014; Tonia et al., 2016). Scientists' impact scores also have been found to improve with increased interaction with reporters being mentioned on Twitter, and interaction with members of the public if it is mentioned on Twitter (Liang et al., 2014). Others have noted, however, that the science community is slow to change the way it communicates, for a variety of reasons, even though scientists see the value in communicating the work they do (Peters, 2012b, 2013).

Organized uses of social media According to a review of research focused on climate change communication online and via social media (Shafer, 2012), social media are important for the strategic communication of a variety of stakeholders, although substantial gaps in the research in this area exist. In the research reviewed, however, climate scientists and scientific institutions played a minimal role in online debates, and their activity was limited primarily to blog writing. Nongovernmental organizations are much more prominent online communicators, but less is known about the climate communications of other corporate and government stakeholders. Research is beginning to examine the impact of government science communication online as well, particularly in response to crises (e.g., Ebola and lead contamination in Flint, Michigan) (Dalrymple et al., 2016).

Individuals and organizations can use social media to facilitate the spread of unverified rumors and myths (Del Vicario et al., 2016). Further, those who use these channels to communicate about science-related controversies can disproportionately be people with views counter to the scientific consensus (McKeever et al., 2016). Other research has found that the communication on social media also is prone to the "spiral of silence," the phenomenon whereby individuals are hesitant to speak out if they feel that a majority of other people do not share their views (Hampton et al., 2014).

Social Networks

Social networks long predate web-based platforms such as Facebook and Twitter. Social networks generally are the web of connections and relationships people have with others—connections that vary in strength (Kümpel et al., 2015) and provide a means for social influence (Contractor and DeChurch, 2014). The importance of networks in policy systems is discussed in

Chapter 3. But given that all people exchange information through such connections, social networks may offer science communicators a means of reaching audiences who do not follow journalistic media or use web-based platforms. These underserved audiences (generally less educated and less affluent) can potentially be served by the astute use of their social networks to transmit accurate and useful scientific information and to counteract falsehoods and distortions.

The spread of beliefs, attitudes, and behaviors through networks has been observed in the areas of obesity, alcohol consumption, and smoking, as well as political mobilization and cooperation (Christakis and Fowler, 2013). Researchers have used social network analysis to determine statistically how these networks exert influence on individual behaviors. This work remains the subject of debate. Some have suggested that the noted effects, attributed to the influence of social networks, may have other causes, such as homophily, or the tendency of people who have common interests, traits, and characteristics to make similar decisions (Aral et al., 2009; Noel and Nyhan, 2011; Shalizi and Thomas, 2011).

The influence of opinion leaders in social networks is another means by which these networks affect individuals, and has been tapped in efforts to disseminate information from science to improve public health (Contractor and DeChurch, 2014). Such approaches hold promise for communicating scientific information effectively to improve the impact of science on public welfare. One study found that nonscientists are more likely to share scientific information with others in their networks when it arouses emotion, or seems useful or interesting to lay audiences, for example (Milkman and Berger, 2014).

With one in seven people worldwide regularly using digital communication platforms such as Facebook, an empirical understanding of how science-related content is communicated within and across social networks is crucial. This understanding may be particularly useful for reaching audiences who are less likely to engage with science-related content in mass media or other traditional channels. Thus online social networks afford a number of opportunities for future research. More systematic analysis is needed of how people understand and perceive science through social media and their social networks. Such tools as social network analysis (Watts and Dodds, 2007) could be used to document the flow of science-related information and sentiments in social networks (Runge et al., 2013; Su et al., 2016) and assess its effects.

Blogs

Science-related blogs have served as one way for highly motivated segments of the public to learn about, follow, and discuss science. These blogs blend the textual depth of online newspapers with the graphical and video capabilities of television, and they enable readers to interact in real time with the blog’s author. Posts also can be written quickly and immediately, responding to new events, issues, or debates, and bypassing the need to convince a journalist to write about or an editor to publish an op-ed on the topic.

Still, data on broader public consumption of science-related blogs are limited, and those studies that do exist suggest that blog reading occurs among a small, unique segment of the public. This population is not necessarily drawn to science blogs for their discussion of science. Many individuals who seek out science blogs may be looking for discussion of the politics of such topics as evolution, atheism, and climate change instead of wishing to learn about science more generally (Su et al., 2014).

Then again, science blogs may be more likely to reach scientists, funders, decision makers, and journalists than the general population. A 2009 Pew Research Center survey of members of the American Association for the Advancement of Science about the state of science and its impact on society found that although only 9 percent of respondents wrote a science blog, 42 percent read such a blog very often or occasionally (Pew Research Center, 2009a). Other research suggests that journalists often use science blogs as a source of story ideas or to track specialized areas of research (Fahy and Nisbet, 2011). In other research, positive relationships were observed among news coverage, social media mentions, and a scientist's total citation impact scores (Liang et al., 2014).

EMERGING RESEARCH ON USE OF THE INTERNET AS A SOURCE OF SCIENCE NEWS

Research on how changing online news environments have influenced the way scientific information is communicated is still in its infancy. Initial studies suggest that the promise of more easily available scientific information does not necessarily translate into more effective science communication (Brossard and Scheufele, 2013). The emerging research on the use of the Internet as a source of science news can be grouped into at least three broad areas: preference-based effects, contextualized news, and widening knowledge gaps.

Preference-Based Effects

Preference-based models of media effects focus on the use of data on people’s behavior (by media organizations or by audiences themselves) to tailor information to the preferences of different audiences (Cacciatore et al., 2016). In online communication environments, information is increasingly tailored to specific audience members based on data on location, prior search history, click rates, shopping behavior, and a host of other personal information (Lazer, 2015; Pariser, 2012). While much attention has been focused on concern about algorithms affecting social media news feeds, even traditional news outlets rely on algorithms to make decisions about news selection or placement, a phenomenon that has been termed “algorithms as editors” (Peters, 2010). Tailored or narrowcast online messaging may be more likely to reach audiences than messaging in traditional broadcast models because, relative to traditional media, online environments make it easier for audiences to select news sources consistent with their beliefs and preferences (Yeo et al., 2015). As a result, people are more likely to pay attention to these messages once exposed to them (Cacciatore et al., 2016; see the discussion of motivated reasoning in Chapter 3). Some empirical work combining search histories from Nielsen NetRatings, Google recommendations, Google search results, and analysis of web content, for example, has shown that the way popular search engines such as Google present search results affects the scientific information people are likely to encounter (Brossard and Scheufele, 2013). In addition to concerns that algorithms may provide only information that consumers find agreeable, algorithms may lead people to what is popular rather than to what is most accurate and useful (Downs et al., 2008; Ladwig et al., 2010). These feedback loops limit the diversity and quality of the information people encounter when they search, a phenomenon that is particularly disconcerting given the above-noted prevalence of search engines as a source of information about science (Brossard and Scheufele, 2013).

In addition to the tailoring of news for particular audiences, online channels, such as news aggregators and social media, give audience more efficient tools than they had with traditional media, such as television and newspapers, for preselecting the types of content to which they would like to be exposed (Scheufele and Nisbet, 2002). A recent study examining public reactions to silver nanoparticles, for instance, offered respondents the opportunity to select from a given set of background articles on the topic before answering more questions. Each article was randomly assigned an ideological cue about the source (conservative, liberal, or neutral), similar to what would be provided by a news aggregator such as Feedly, Flipboard, or Google News. In line with the concept of preference-based selection, conservative respondents in one study were more likely to select Fox News as their first information source, regardless of content, while liberals were significantly more likely to select MSNBC (Yeo et al., 2015). In other words, people's tendency to attend disproportionately to news content coming from ideologically consistent sources is further enabled by new information environments that allow them to make this selection with limited effort, and before even seeing any content with which they might disagree.

Contextualized News

Research has examined the influences of social feedback on how science news is used. Research in communication science, social psychology, and related fields has shown that people's perceptions of social norms (i.e., their sense of appropriate or expected behaviors and attitudes) shape their own behaviors and attitudes (Noelle-Neumann, 1993; Sherif, 1967; Schultz et al., 2007). Online news environments have allowed for almost instantaneous social feedback through Facebook likes, YouTube views, reader comments, Reddit upvotes, and retweets on Twitter. An emerging body of research suggests that this social contextualization of news can have a significant effect on how audiences view and process science news. Work on what has been called the "nasty effect," for instance, has shown that being exposed to uncivil reader comments on objective scientific reporting on a topic can increase readers' perceptions of bias in the story itself and can even polarize perceptions of the risk associated with the topic of the story (Anderson et al., 2014; Brossard, 2013; Brossard and Scheufele, 2013).

Cues that signal the accepted social norms related to a topic can be much more subtle than explicitly uncivil comments. The simple number of views for YouTube videos is an example of such a cue. A recent study, for instance, linked the number of views listed under YouTube videos about climate to perceptions of how "others" feel about the climate issue. The number of views cue did more than influence perceptions of other Americans' thinking on the importance of climate change as an issue. Among those respondents who were generally more responsive to social cues, this cue increased their own judgments about the issue's importance (Spartz et al., 2015b).

Widening Knowledge Gaps

Evidence indicates a persistent knowledge gap with respect to new media between less-advantaged people and those with higher socioeconomic status and more education (Cacciatore et al., 2014; Eveland and Scheufele, 2000; Slater et al., 2009; Tichenor et al., 1970). This knowledge gap reinforces status quo differences in resources and participation in society's conversations about contentious issues and the related science. Science communicators need to consider this gap in planning how to engage segments of the public not already attending to or interested in science as a topic. People who visit museums, watch documentaries such as *Nova Science Now* on the Public Broadcasting Network, or attentively read the science coverage of a national newspaper are an easy audience to reach. But they are not the majority of the American population, and in education and wealth, they represent a kind of elite.

Research has documented that differences in how scientific information is used and processed can, in fact, widen gaps in knowledge among groups. In particular, groups with higher socioeconomic status process and absorb new information more efficiently than groups with lower socioeconomic status. As a result, existing gaps in knowledge widen as new information becomes available, since audiences with higher socioeconomic status also tend to have more informed discussion networks to help them make sense of new information or bring knowledge that allows them to process new information more efficiently (Corley and Scheufele, 2010; Nyhan et al., 2013; Scheufele, 2013). Early research also suggests, however, that Internet-based sources of scientific information can be more accessible to diverse audiences regardless of socioeconomic status and help narrow knowledge gaps produced by more traditional outlets (Cacciatore et al., 2014).

Research is needed to understand how individuals and decision-making bodies derive and evaluate information from various media sources. Research also is needed to determine how science communicators can be heard among many competing sources of information, messages, and frames. Further, are some forms of media better than others in promoting awareness or understanding of or informing public opinion about science and scientific information, and for whom?

5
Building the Knowledge Base for Effective Science Communication

As science and technology have become increasingly embedded in every aspect of modern life, recognition of the need for effective communication of science to the public and policy makers has grown. As reviewed in this report, a moderate body of scientific literature is available to inform efforts to communicate science, but many unanswered questions remain. This chapter summarizes the major challenges for science communication and needs for research identified throughout the report, with the aim of providing a potential research agenda for both funders and scientists.

A widespread assumption in both the scientific and science communication communities is that communicating science well will affect public understanding of and attitudes about societal issues. However, this assumption has not been tested extensively, and it needs to be. Measurement of the effectiveness of science communication is discussed in more detail later in this chapter.

A research effort also is needed in which researchers and practitioners of science communication form partnerships to translate what has been learned through research into practice and develop research agendas for testing realistic and pragmatic hypotheses about how best to communicate science. Models for organizing such translational research include the National Institutes of Health's National Center for Advancing Translational Sciences and initiatives of the National Science Foundation that encourage partnerships between university researchers and professionals working in education or industry. Such an effort also could inform training for science communicators.

The committee's task was to review research related to science communication in order to develop a research agenda for the future; thus, the committee was composed mainly of scientists. We engaged a wide range of science of communication practitioners at different points in the study process, including through public committee meetings, email, and telephone discussions and as expert reviewers of the draft report. In public meetings, we also gathered insights from policy makers, who are an important audience for science communication. Our hope is that the agenda described in this report will stimulate discussion among science communicators, researchers, and research funders focused on establishing priorities for research and practice and identifying ways of implementing the ideas put forth in this report.

The first section of this chapter describes general conceptual and methodological issues that need attention if an evidence base for communicating science is to be built. This report could not be, and is not, a comprehensive review of the scholarship on science communication. As the report shows, however, it is clear that the literatures relevant to communicating science are diverse, disconnected, and at different stages of development. For some topics, research has accumulated such that certain things are known, at least in a particular context for communicating science or for a specific issue. In other cases, the evidence is more indirect. Often the research was performed for reasons other than to inform science communication, and its relevance to that topic is inferred. These insights need to be tested systematically for their relevance to science communication.

In some areas, especially such emerging topics as the roles of social media and social networks, the research base consists of a single or a few studies. Although the studies described herein may be compelling and suggest ideas for practice, it is important not to overgeneralize from their findings. These studies need to be replicated and extended to provide greater certainty about their results and whether they apply to different audiences and circumstances. Two National Academy of Sciences Arthur M. Sackler Colloquia on the Science of Science Communication that resulted in two special issues of the *Proceedings of the National Academy of Sciences* (Fischhoff and Scheufele, 2013, 2014), as well as the convening of this committee, point to the readiness of science communicators and researchers from diverse fields to address this need and work toward science-informed approaches to science communication.

The second section of this chapter presents major unsettled questions surrounding the challenges of effective science communication. These questions are stated at a general level and organized around the major challenges the committee identified. For each, we present examples of more specific questions that, if pursued, would enable science communicators to be more effective in their work. We do not specify, in each case, all of the important questions that would be important to pursue. Rather, researchers need to use their technical expertise and partner with professional science communicators and audiences to identify the most useful detailed questions and feasible methods for addressing each of the major challenges specific to a domain of interest. Such partnerships might involve researchers and science communicators and experts from related communication fields working within government, boundary organizations, university press offices, media, and industry.

The third section of the chapter suggests ways of building the research capacity needed to implement the proposed research agenda. These suggestions for infrastructure center primarily on the need to attract researchers from diverse disciplines to the study of science communication, but there are additional needs as well. Throughout, we offer brief observations on ways in which this research agenda might be used.

GENERAL CONCEPTUAL AND METHODOLOGICAL ISSUES

General conceptual and methodological issues that need to be investigated to build the research base on the science of science communication include developing methods for aligning goals with the right communication approach; using a systems approach to guide research on science communication; assessing the effectiveness of science communication; and conducting comparisons across diverse national, international, and cultural contexts.

Aligning Goals with the Right Communication Approach

As described in Chapter 1, people communicate science for diverse reasons. One goal of science communication is simply to share the findings and excitement of science. A second goal may be to increase appreciation for science as a useful way of understanding and navigating the modern world. A third goal may be to increase knowledge and understanding of science related to a specific issue that requires a decision. A fourth goal may be to influence people's opinions, behavior, and policy preferences—for example, when the weight of evidence clearly shows that some choices have consequences for public health, public safety, or some other societal concern. And a fifth goal is to engage with diverse groups so that their perspectives about science related to important social issues can be considered in seeking solutions to societal problems that affect everyone. A major research effort is needed to help align approaches to science communication with particular goals.

Science communication often is undertaken to achieve a larger end, one that goes beyond discussions of the science itself. Examples include increasing vaccination levels or encouraging a particular policy choice around climate change. It is possible that means other than simply communicating the science may be more effective at accomplishing such goals. The important questions to pursue include, How much does science communication matter to the achievement of end goals relative to everything else that matters? and How do various ways of communicating scientific information augment or alter the ways in which science is weighted or used in decision making?

Using a Systems Approach to Guide Research on Science Communication

Science communication occurs within a complex system whose elements include the content to be communicated, the format in which it is communicated, the diverse organizations and individuals who are also communicating science, the various audiences, the channels of communication, the political and societal realities within which the communication takes place, and the many other sources from which audiences may find additional and perhaps conflicting or inaccurate scientific information. Each of these elements itself is complex, and each interacts with the others in complex and largely unknown ways. Moreover, this system is dynamic and ever-changing, and has unique characteristics depending on the type of science that is being communicated. People's understandings and opinions about science in general and its relevance to specific issues change over time. Political environments and levels of media attention change. And so does the involvement of interest and advocacy groups, regulators, and many other stakeholders.

Research to date suggests that, although each element of the system within which science communication takes place can be studied and to some degree understood individually, research on communicating science is most effective when the various elements are considered as an integrated whole, and thus when a systems approach is taken. A systems approach is typically defined as an "iterative learning process in which one takes a broad, holistic, long-term, perspective of the world and examines the linkages and interactions among its elements" (Institute of Medicine, 2010, p. 74).

A systems approach could help researchers and communicators in science communication consider interactions among the various elements of such communication and the context in which they occur in the real world over time, and go beyond studying each element at one point in time, in isolation. Such a holistic understanding could guide communication efforts that would take the complexity of the system into account (i.e., the level at which the communication should be targeted, who should be involved in the communication, what types of content need to be communicated and how, and even whether there should be any communication at all).

Effective communication about stem cell research, for instance, is difficult without a systems approach. While communication needs to take into account the psychological and cognitive factors that shape attitudes and decisions among individuals, those attitudes and decisions do not develop in isolation. Instead they often are shaped by group-level influences, such as churches or other community groups with unique communication channels and mechanisms of influence (Matei and Ball-Rokeach, 2003). The communication environment surrounding stem cell research is heavily influenced by competing voices and pressures from various stakeholders at the societal level, including political actors, religious groups, and regulatory and funding agencies. Any effort to communicate about stem cell research without taking into account the dynamics within and across these different levels of influence is therefore bound to be less effective than it otherwise would be. And the same dynamics manifest themselves for many contentious issues, including childhood vaccinations and genetically modified organisms. (See Rice and Foote [2001, Chapter 8], for an illustration of a systems-based evaluation planning model for health communication.)

Some of the elements outlined above and their influences will not be predictable or direct, but it should be possible to document enough about them to develop models of how communicating science in certain ways for particular reasons takes place within a larger system of influences. Other fields have used this general approach to advance knowledge and achieve important outcomes (see Institute of Medicine, 2010, Chapter 4). The building and testing of such models can serve as the basis for research using field experiments to test approaches to communicating science in complex communication environments. Following this path will require a robust understanding of both the individual elements of the system and how they interact. At a minimum, researchers focusing at any level of analysis need to be acutely aware of the broader context in which communication efforts are undertaken. More important, however, a systems approach requires that researchers understand empirically the interactions among different elements of the system over time and across and within levels of analysis—individual, group, community, and societal.

This work ideally would begin with in-depth, comprehensive reviews of the evidence related to each of the elements that research indicates could be important to communicating in a particular context to achieve specific goals and how these elements may interrelate, as well as identification of specific gaps in knowledge. These reviews could be used to develop initial hypotheses about how the various elements operate both individually and in their interactions to influence people's responses to particular types of science communication intended to achieve certain goals in specific contexts. Explanatory models of the influences of science communication on individual decisions, for instance, need to specify such elements as the type of decision being made, the factors likely to influence that decision, and when and in what forms scientific information is likely to be useful or not.

Other fields, such as public health and political science, have drawn on such systems thinking. In health communication, for example, systems thinking enables an integrated perspective on how individuals respond to competing messages within a complex and dynamic social and political environment, and how those messages propagate through and evolve in interpersonal networks and other social groups. Research on science communication has paid comparatively little attention to approaches based on systems thinking. Given the complexities and multilevel nature of the problems faced by the science communication community, the committee advocates a renewed focus on such approaches for the study of science communication and an empirical research program aimed at informing these efforts. Examples of major questions a systems approach could be used to answer include the following:

- How do the various elements involved in communicating science at the individual, group, community, and societal levels interact to affect how people understand, perceive, and use science?

- How do different types of audiences respond to various attempts to communicate science amid science-related controversy depending on the nature of the controversy; the type of decision to be made; the state of the relevant science (e.g., whether emerging or well developed); and the types of values, beliefs, and organized interests involved.

Assessing the Effectiveness of Science Communication

Most research on science communication conducted to date is descriptive and correlational, and relatively little of the existing research can enable confident statements about causality. This limitation is not unique to research on science communication, but characterizes much of the study of communication more generally (Fischhoff, 2013). It is especially important to investigate questions about science communication using multiple methods. For example, surveys of representative samples of the population allow for broad generalization, but unless changes in individuals are tracked over time, drawing strong causal inferences on the basis of survey results can be challenging. In contrast, controlled experiments allow for strong conclusions about causality, but even in the case of field experiments and certainly in the case of laboratory experiments, the degree to which they can be generalized to a wider public is uncertain. Thus, strong conclusions emerge from triangulating across multiple methods. Moreover, the nature of some of the questions posed in this report—particularly those that relate to effects on policy and on groups as opposed to individuals—makes them unlikely subjects for the kinds of randomized designs that are considered the gold standard for determining causality. Therefore, it will be important to use a combination of methods that over time will allow strong inferences to be drawn about how audiences respond to various approaches to communicating science. Substantially more research is needed to determine which approaches are effective for whom, when, and under what conditions. This knowledge should yield general, evidence-based principles for how to communicate science effectively and how to adapt science communication to particular audiences and contexts to achieve specific goals. Research focused in the following ways would be especially informative:

- Both one-time and longitudinal cross-sectional surveys using representative samples can provide information about people's understanding, perception, and use of science that can be generalized to the larger population, as well as an understanding of how those measures change over time.
- Randomized controlled field experiments can be used to assess the impact of a particular approach to communicating on changes in people's understanding, perception, or use of science, or any other important outcomes.
- Research needs to simulate to the extent possible the conditions of real-world communication environments.
- Effectiveness research that includes in-depth description of the contexts in which the science communication being investigated occurs can support inferences about other conditions to which the findings might apply.
- Studies in science communication frequently use convenience samples, such as undergraduate students or Mechanical Turk Service samples. It is important to select samples carefully so that findings can be generalized across segments of the population who are the intended audiences for the communication.

- Better measures of the quality and effectiveness of science communication are needed, keeping in mind that whether such an effort is effective depends on the goals of the communicator and that the communicator and the target audiences may define successful communication differently (for example, when the audience seeks information from science, but the communicator seeks also to persuade).
- Analyses of large datasets such as those derived from social media and other emerging online communication platforms could be useful for collecting information needed to assess changes in people's understandings and perceptions of science related to social issues. These changes might be useful for predicting changes in related behaviors or decisions.

Finally efforts are needed, perhaps in the form of registries, to aggregate findings from effectiveness research and catalog studies according to key dimensions so that approaches used for this research and the evidence produced can be shared more easily, serving as a foundation for future work. Developing such tools would enable building an evidence base that would identify key factors that affect science communication and the elements of various approaches to communicating that may generalize across topics or be specific to certain types of circumstances. At present, moreover, it is challenging to find all that is known from research related to science communication. Efforts also are needed, therefore, to help researchers access and utilize relevant research across disciplines. Registries such as those that exist in the health sciences for original studies, research reviews, and research protocols could help with this task.

Comparing across National, International, and Cultural Contexts

Analysis and comparison of diverse national, international, and cultural contexts can yield important insights into science-related controversies and emerging issues that are global in scope. Some issues, for example, are highly contentious in some places but not others, and contexts differ in how issues have been framed and in the success with which science communication has been used. Comparing contexts can provide insights into a broad range of factors that cannot be gained from analysis within a single context (McCright et al., 2016, e.g., see Arnold et al., 2016; Gaskell et al., 2000). Comparing approaches to communicating science across contexts also can help identify overarching principles that hold across contexts and those that are specific to controversies at the local, national, and international levels. At the same time, however, it bears noting that these kinds of cross-context studies are among those that pose particular challenges for experimental research designs.

MAJOR CHALLENGES FOR PRACTICE AND RESEARCH IN SCIENCE COMMUNICATION

Major challenges for practice and research in science communication include understanding the converging influences on science communication; engaging formally with the public about science; understanding the special complexities of communicating science in the face of public controversy; and communicating science in a complex, dynamic, and competitive communication media environment. Following are the committee's conclusions about the factors relating to each of these challenges that need to be understood.

Understanding the Converging Influences on Science Communication

Most people do not pay attention to science regularly, although they encounter and benefit from it in their everyday lives. They seek to make sense of it only when it is important to a decision they must make as individuals or in the context of institutions in which they have a role—as consumers, patients, parents, voters, or policy makers.

Research to date has pointed to a number of factors that make it challenging to communicate science effectively to diverse audiences regardless of whether the science relates to a public controversy:

- Some challenges stem from the complex nature of scientific information, such as the uncertainties inherent to science, and the ways in which people process such information. People, for example, often are unsettled by the ambiguity of science, and tend to have difficulty understanding scientific uncertainty and probability. Uncertainty has a number of sources, including ambiguity about the weight of evidence, uncertainty about future outcomes arising from probabilistic evidence (risk), and uncertainty about the degree to which scientific evidence applies to a particular context or has personal significance. Continued research can resolve some uncertainty by providing additional information, but in other cases, and especially with complex problems involving science, uncertainty will persist.
- As discussed in Chapter 2, people in general use shortcuts to make sense of large amounts of complex scientific information. They hold a variety of beliefs and values that shape their interpretations of new information and that, while usually adaptive for navigating a complex world, can lead to inaccuracies in their interpretation of scientific information, especially when uncertainty is involved.
- Also as noted in Chapter 2, people have a strong tendency to confirm their existing ways of thinking, a tendency that makes a decision or attitude resistant to change.
- In science communication, as with other types of communication, the audience decides whether the sources of information or the institutions they represent are trustworthy. People use this assessment in deciding what information is worth their attention, and often what to think about that information.
- People's opinions and decisions also are affected by a variety of social influences—social networks, norms, group memberships, and loyalties.

Further study is needed to determine the extent to which each of the above factors matters to communicating science in particular contexts to achieve specific goals. Research also is needed to determine the importance of these factors relative to others (discussed in Chapter 3) that come into play when science is involved in controversy.

Many of the decisions to be made about societal issues occur at the level of policy. Information about the impact of science communication on policy decisions, however, is sparse. One reason for this gap is that in a complex policy-making environment, it is difficult to know whether a particular communication affects a decision. Important questions, perhaps more feasible to address, are, How is scientific information accessed, encountered, understood, shared, and discussed by policy makers in formal policy processes? How can science communication affect these processes? and How are these processes affected by science communication when the science is involved in public controversy?

Think tanks, scientific associations, evidence-based clearinghouses, government agencies, industry groups, and nonprofit organizations all play an organized role in aggregating, translating, and interpreting such information for use by policy makers, the media, and the broader public. Research is needed on the conditions for success in the efforts of diverse types of organizations to communicate science. For example, what effects do boundary organizations have on the quality or outcomes of policy discussions of science-related issues?

Engaging Formally with the Public about Science

The purpose of formal public engagement aimed at bringing the general public into discussions with scientists about important science-related issues is to facilitate the exchange of information, knowledge, perspectives, and preferences among groups that differ in expertise, power, and values (National Academies of Sciences, Engineering, and Medicine, 2016b) and to find common ground (see the detailed discussion in Chapter 2). This type of dialogue with the public is especially important when the science is emerging and has uncertain implications for society or when the science is involved in public controversy (discussed in Chapter 3 and below).

As noted in Chapter 3, formal public engagement is difficult to do well. That chapter presents principles for public engagement derived mainly from the literatures on environmental assessment and decision making, and most of this evidence was derived from public engagement activity at the local and regional levels. As public engagement is undertaken on such diverse issues as gene editing, climate change mitigation, biomedical research, and health policy, important questions for research are, What are the particular structures and processes for public engagement that enable science to be communicated effectively? and To what degree do these approaches generalize or need to be tailored according to the diversity of the participants, the decisions to be made, and the nature of the topic.

Understanding the Special Complexities of Communicating Science in the Face of Public Controversy

The involvement of science in public controversy makes the already complex task of science communication even more so. Science-related controversies take many different forms and arise for diverse reasons, as described in Chapter 3. Although this report has identified features of science-related controversy that make communicating science especially challenging, more needs to be understood about the origins and dynamics of these controversies if science communication is to be more effective. The following are examples of questions to pursue:

- What factors contribute to the emergence of science-related controversies? To what extent do these controversies originate with the scientific community as opposed to broader political, economic, or social arenas?
- Why do some controversies involving science gain traction and persist while others do not?
- How do people's perceptions about science change over time as science-related controversy evolves, and why? What are the factors (individual, social, contextual) that affect the extent to which perceptions about scientific information will become contentious and perhaps polarized?

- How much does the cause of a science-related controversy matter to the approaches that will be effective in communicating science related to that issue? Are there categories of causes of science-related controversy that communicating science can help address? Which approaches to communicating science related to contentious issues are effective, and which are not?
- The organizations and individuals that communicate science related to controversy are diverse, and they have various reasons for communicating. How do the different messages from various sources interact to affect peoples' responses to scientific information over time?
- How do public controversies involving science resolve? Under what conditions does the communication of scientific information have an impact on the resolution of a debate by changing people's understanding or opinions?

Science-related controversies defy easy typology. Nonetheless, as described in Chapter 3, the committee concludes that science-related controversies have three features about which more needs to be known: (1) conflicts over beliefs, values, and interests are central to the debate, rather than simply a need for knowledge from science; (2) the public perceives uncertainty either in the science, in its implications, or as a result of communicators saying different and sometimes contradictory things in the public sphere; and (3) the voices of organized interests and influential individuals are amplified in public discourse and impede making the state of the scientific evidence clearly known.

Each of these features is discussed in turn below, and major questions that need to be addressed by research to develop effective approaches to communicating science are identified. In general, it will be important for research to determine whether the answers to these questions differ by issue (e.g., climate change versus vaccination); by the scale of the controversy (e.g., local versus national versus international); by the nature of the decision-making institution (e.g., Congress versus executive agencies versus the courts; local versus state versus national government versus private-sector organizations); and according to differences in audiences' beliefs, values, world views, levels of trust, and mental models.

Conflicts over Beliefs, Values, and Interests

As discussed previously, across many different science-related controversies, audiences and individuals with differing beliefs, values, and interests may respond in quite different ways to the same scientific information. In some circumstances, continuing to communicate what is known from science can lead people to believe misinformation about science more strongly, making it even more difficult to communicate for a better understanding of scientific information. When conflicts over beliefs, values, and interests are central to people's decisions, how can science be communicated effectively? In these contexts, how much of an effect can science communication have, for whom, and in what circumstances?

Communicating science effectively in contexts of conflict requires that the audience perceive science and scientists as trustworthy and credible. What factors affect trust in and the credibility of scientists and scientific information when science is involved in controversy? In such cases, what are the effects of science communicators being open about their own values and preferences? How might efforts to persuade people to adopt scientifically supported positions affect their perceptions of scientists? What are the best strategies for communicating science related to controversial issues in the face of distrust of the science or of the scientific community?

Public engagement is one approach for addressing conflicts over beliefs, values, and interests related to science. Yet given that best practices in public engagement suggest engaging with stakeholders early on, an important unanswered question is, To what extent and in what ways can communicating science in formal public participation processes be effective once an issue has become controversial?

Finally, public engagement in discussions about controversial science-related issues has in many cases resulted in a set of principles for structuring such discourse to achieve particular outcomes. Much of this research, however, has focused on environmental assessment and decision making. What are the elements of effective structures and processes for communicating science effectively in public forums across a range of social issues (e.g., biomedical research, health policy, gene editing, education policy) and types of controversies? Audiences from the same group or community may be internally diverse in their values, interests and experiences. How do the characteristics of groups or communities affect their responses to science communication and different approaches to their engagement?

Uncertainty in Science Related Controversy

As discussed in Chapter 2, communicating scientific uncertainty is a substantial challenge in all instances of science communication. Amid controversy, however, uncertainty about risks and other aspects of the science can be particularly problematic, as described in Chapter 3. This uncertainty can easily be mischaracterized, exploited, or exaggerated to serve particular interests. Research on how to communicate scientific certainty or consensus effectively in science-related controversy is just emerging, and thus important questions remain, including the following:

- What are effective ways of communicating scientific consensus and talking about degrees or types of uncertainty about scientific information in cases of science-related controversy?
- Progress is beginning to be made toward understanding the different ways in which people respond to attempts to communicate scientific information amid controversy. However, there is a need to develop detailed approaches to understanding audiences' responses to uncertainties about science in cases of science-related controversy that could be implemented on a large scale.

Amplified Voices in Science-Related Controversy

Science communication may take into account the beliefs and values of varied audiences and communicate well about where the weight of scientific evidence lies, but still be ignored or disregarded in discussions concerning contentious issues. High stakes, conflicting interests, uncertainty, and concerns about risk and its consequences can expand the number and diversity of people and organizations that are attempting to communicate about science, as well as the number of parties who use scientific information (whether appropriately or not). In this kind of context, misinformation about science can make it difficult for an authoritative voice from science to be heard. Research is especially needed in the following areas:

- Misinformation about science stems from misunderstanding as well as deliberate efforts to misconstrue the science. Debunking such misinformation is difficult. Research is beginning to suggest some strategies to this end and for whom they may work. Yet a better understanding of effective strategies for correcting misinformation is needed.
- What are effective ways of framing scientific information in science-related controversies? How much does framing of an issue matter, and when is it best done?
- Opinion leaders are important voices in the community, but working with them to convey scientific information may also pose a risk to the credibility of scientists. How do different types of opinion leaders affect people's understanding of scientific information and its use in their decision making?

Communicating Science in a Complex, Dynamic, and Competitive Communication Media Environment

As described in Chapter 4, science communication takes place today in a complex and rapidly changing media environment. More than ever, many voices are competing for the attention of various audiences on all topics, including science. Patterns of news use are changing, and with them structures in commercial journalism. These developments are especially dramatic for science news. At the same time, new ways of communicating are constantly emerging online, with lower costs for dissemination, new modalities and reach, and fewer central gatekeepers setting frames and agendas. These new forms of communication entail new challenges and offer new opportunities for drawing attention to and shaping people's opinions about science related to contentious issues.

The way changes in media affect people's engagement with scientific information related to social issues is an emerging area of research. The research to date has focused on several themes: how individual preferences and other characteristics of audiences shape the selection of media, media sources, and science content online; how social interactions and norms of online communities affect people's engagement with and views of scientific information; and how media create and spread misinformation or accurate scientific information. Research is needed to understand how individuals and decision-making bodies derive and evaluate information from various media sources. Such research will need to keep pace with change in the media landscape, devise more comprehensive models of news and social media, and yield more information about news-sharing networks. Major questions for future research in this area include the following:

- How can accurate information about the state of the science be heard among many competing messages and sources of information? Given that the news people seek and encounter online is increasingly tailored to their preferences, how can science be communicated to ensure that people encounter and have access to information when they need it?
- Are some forms of media better than others at promoting awareness or understanding of or informing public opinion about scientific information, and for whom? For example, how do these effects vary according to characteristics of the audience, such as their values, group affiliations and loyalties, tendency to "think like a scientist" about scientific information, and various demographic characteristics?

- How can science communicators reach audiences that face barriers to accessing and using scientific information, such as those with lower levels of education and income?
- Much of the scientific information Americans receive through media still originates from traditional journalism. Journalistic decisions about what to cover, how to convey different perspectives, how much and how long to cover an issue, and how stories are framed can affect the public's perception of science, the issues that should be of concern to them and on the public agenda, and how they judge the credibility of scientific information and the scientific enterprise. For these reasons, it is important to understand and track over time how science is covered in the media in order to determine how the media are affecting people's perceptions, understanding, and use of science in a dynamic communication environment. Relatively more is known about journalistic decisions and their effects with respect to traditional news coverage, but how do these decisions operate and affect audiences for scientific information in rapidly changing online environments?
- Social media and science blogs increasingly are being used to spread both accurate information and misinformation from science. More research is needed to determine effective approaches for communicating science on social media platforms and through blogs.
- Social networks are the web of connections and relationships that people have with others—connections that vary in strength and that provide a means for social influence. People's beliefs, attitudes, and behaviors can be affected through networks that include opinion leaders. While this has long been the case, it is likely that social media affect the assembly and effects of these networks. Future research needs to examine the effects of changes in media on how people understand and perceive science through social media and other social networks. Such tools as social network analysis could be explored for documenting the flow of information and sentiments in social networks and assessing their effects.

The following are additional examples of questions to be addressed by research to gain a better understanding of the complex and changing media environment:

- What impact do social media have on people's understandings and perceptions of science and their use of scientific information in making decisions? How do the features of social media that limit exposure to diverse sources of information and perspectives (such as filter bubbles and echo chambers and curated Facebook feeds) influence people's perceptions of science and their ability to access, understand, and use scientific information for decision making? What are the implications for how scientific information is best communicated?
- What role can digital technologies play in presenting scientific information more effectively? New software, for example has facilitated the development of interactive graphical depictions of information that can be diffused online. How can such graphics be used more effectively, for whom are they helpful, and under what circumstances?

Additional Questions for Research

The following are examples of additional questions to be answered about the challenges of science communication, whether on contentious issues or not:

- What aspects of science literacy matter to effective science communication? How do characteristics of individuals, such as skill with numbers (numeracy) or prior knowledge of science, affect their processing of scientific information? How do the effects of these individual differences vary depending on how scientific information is presented, such as the use of different visual presentations?
- How important to effective science communication is people's understanding of the nature and processes of science? Does understanding the nature of science actually translate into the use of scientific information in decision making or other aspects of life? Does having some ability to "think like a scientist" about scientific information affect people's responses to such information or their use of it when making decisions? Is it important, for example, to have certain understandings about scientific methods, to have certain competencies in decision making using science, or to be able to interpret information about probabilities? Are these understandings and competencies more and less important under particular circumstances, such as amid science-related controversy?
- Many assume that having knowledge about the science related to an issue will affect people's attitudes on the issue. What specific types of knowledge about science might affect attitudes on an issue? Are some types of attitudes important to address first so that audiences are open to understanding the science and considering it for a decision? Do previously held attitudes or knowledge related to the science predict personal decisions or policy choices, and under what circumstances?
- Research on framing confirms that how an issue is cast can affect public attitudes and behaviors with respect to that issue, but findings on the effects of framing on specific attitudes or other measures of support for particular positions related to social issues are mixed. What role does framing play in shaping people's understanding of scientific information?
- How can science communication reach and be tailored to meet the needs and concerns of audiences that vary by race, ethnicity, language status, income, and education level and that may respond differently to science as a result of differences in their norms, beliefs, or experiences?
- What factors influence audience perceptions of trust in science and scientific information? How does trust vary depending on the communicator, the goals for communication (e.g., informational versus persuasive), and the communication context? How does trust change as the science on an issue is communicated over time?
- Which types of science communicators are most effective in what settings? In what circumstances is it important for scientists versus others to serve as the communicators?
- What are the core competencies of an effective science communicator, depending on the goals for communicating, the setting, and the target audiences?

- To what extent are the opinions of different audiences influenced by perceived problems within the scientific community, such as limits on the reproducibility of research findings, scientific fraud, or conflicts of interest.

BUILDING A COHERENT SCIENCE COMMUNICATION RESEARCH ENTERPRISE

As discussed in Chapter 1, a productive but relatively small and evolving community of researchers now studies science communication, but research capacity needs to grow and research methods to evolve if real progress is to be made. Some of that growth can be promoted through infusions of funding, but there are other needs as well. For example, researchers and practicing science communicators need opportunities for the regular exchange and synthesis of information and ideas so as to keep the research agenda current and useful. The varied disciplines that study science communication and science-related controversies need opportunities and mechanisms for working together to develop more unified theories, concepts, and definitions of the factors that matter to communicating science and their influences. Science communication needs to be studied in real-life contexts, where it occurs, using methods that can directly address practical issues of how best to communicate science information. If science communicators are to find research useful, they need to work with researchers to develop specific research questions that are guided by scientific theories and knowledge and that address the communicators' goals and concerns.

New or refocused journals for research on science communication and professional meetings and other forums would support practice-driven research collaborations even more than existing journals currently do, with publications being tailored more explicitly to interdisciplinary audiences outside the field of science communication. Progress will require that these activities not be supported in isolation or be ad hoc, but designed strategically and sustained for long enough to build a coherent community and a base of scientific knowledge that can be useful for science communication practice.

To enable full exploration of the complex phenomena whose understanding will provide an appropriate knowledge base for effective science communication, more scientists need to be recruited to this field from neighboring disciplines, particularly the social and behavioral sciences. Again, more active engagement of the diverse professionals and organizations that communicate science for different reasons and in different contexts is needed. Ideally, this research agenda would be pursued by researchers working with different types of boundary organizations, issue networks, agencies, media organizations, and other entities that communicate science.

One of the challenges of conducting research on science communication is the long delays between proposing projects and their being funded. Mechanisms for ensuring rapid review and funding of such research are sorely needed, particularly when issues, such as the Zika virus, emerge suddenly, and important messages from science need to be communicated. Not all barriers to accelerating such research concern funding. Institutional structures and regulatory policies also can make timely research difficult. One example is the requirement to obtain approval by the Office of Management and Budget for gathering data from the public under the Paperwork Reduction Act. In addition, new mechanisms for research collaborations could be developed following such models as the National Oceanic and Atmospheric Administration's program on Regional Integrated Sciences and Assessments or extension models of land grant institutions that have supported partnerships between communities of researchers and decision makers for the design and conduct of research aimed at solving complex practical problems. As described in Chapter 2, private foundations also have funded partnerships between researchers and policy makers to close the gap between research and people's use of research results. Such partnerships recognize the need to go beyond the simple model of communication described in Chapter 1 to produce knowledge that is useful and communicate it to those who make or influence decisions.

Finally, science communication researchers at all career levels may need additional training to develop the methodological and professional expertise necessary to carry out the research agenda proposed in this report. Alternatively, they could be encouraged to work in teams including other partners with the necessary expertise. Similar efforts at training or fostering collaboration among researchers with diverse methodological expertise have been undertaken successfully by the U.S. Department of Education's Institute of Education Sciences and by the National Institutes of Health when they have seen a need to build the capacity of the research community to respond to requests for proposals. Training efforts have included offering or sponsoring courses or workshops and supporting enhancements to doctoral or postdoctoral training programs.

FINAL THOUGHTS

As science has come to touch the everyday lives and decisions of individuals and institutions and as more people are attempting to communicate about science, science has become part of public discourse as never before. The need to communicate science effectively—for the sake of the public, policy makers, and the science community itself—lends urgency to the implementation of the research agenda proposed herein. This agenda will be implemented only if the institutions that communicate science and public and private funders of research become committed to strengthening the science of science communication and working toward evidence-based practices. It is the committee's hope that this report will stimulate that commitment.

References

Allum, N., Sturgis, P., Tabourazi, D., and Brunton-Smith, I. (2008). Science knowledge and attitudes across cultures: A meta-analysis. *Public Understanding of Science*, *17*(1), 35-54.

Am, H. (2013). Don't make nanotechnology sexy, ensure its benefits, and be neutral: Studying the logic of new intermediary institutions in ambiguous governance contexts. *Science and Public Policy, 40*(4), 466-478.

Anderson, A. A., Kim, J., Scheufele, D. A., Brossard, D., and Xenos, M. A. (2013). What's in a name? How we define nanotech shapes public reactions. *Journal of Nanoparticle Research, 15*, 1421.

Anderson, A. A., Brossard, D., Scheufele, D. A., Xenos, M. A., and Ladwig, P. (2014). The "nasty effect": Online incivility and risk perceptions of emerging technologies. *Journal of Computer‐Mediated Communication*, *19*(3), 373-387.

Aral, S., Muchnik, L., and Sundararajan, A. (2009). Distinguishing influence-based contagion from homophily-driven diffusion in dynamic networks. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(51), 21544-21549.

Arnold, A., Böhm, G., Corner, A., Mays, C., Pidgeon, N., Poortinga, W., Poumadère, M., Scheer, D., Sonnberger, M., Steentjes, K., and Tvinnereim, E. (2016). *European Perceptions of Climate Change. Socio-Political Profiles to Inform a Crossnational Survey in France, Germany, Norway, and the UK*. Oxford, UK: Climate Outreach.

Asensio, O. I., and Delmas, M. A. (2015). Nonprice incentives and energy conservation. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(6), E510-E515.

Baram-Tsabari, A., and Segev, E. (2009). Exploring new web-based tools to identify public interest in science. *Public Understanding of Science, 20*(1), 130-143.

Bednarek, A. T., Shouse, B., Hudson, C. G., and Goldburg, R. (2016). Science-policy intermediary from a practitioner's perspective: The Lenfest Ocean Program experience. *Science and Public Policy*, *43*, 1-10.

Bekker, H. L., Winterbottom, A. E., Butow, P., Dillard, A. J., Feldman-Stewart, D., Fowler, F. J., M. L. Jibaja-Weiss, V. A. Shaffer, and Volk, R. J. (2013). Do personal stories make patient decision aids more effective? A critical review of theory and evidence. *BMC Medical Informatics and Decision Making*, *13*(Suppl. 2), S9.

Bennett, W. L. (2016). *The Politics of Illusion* (10th Edition). Chicago, IL: University of Chicago Press.

Berkman, M., and E. Plutzer. (2010). *Evolution, Creationism and the Battle to Control America's Classrooms*. New York: Cambridge University Press.

Bernauer, T., and McGrath, L. F. (2016). Simple reframing unlikely to boost public support for climate policy. *Nature Climate Change*. Available: http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2948.html [November 30, 2016].

Besley, J. C. (2010). Public engagement and the impact of fairness perceptions on decision favorability and acceptance. *Science Communication, 32*(2), 256-280.

Besley, J. C., and McComas, K. A. (2015). Something old and something new: Comparing views about nanotechnology and nuclear energy. *Journal of Risk Research, 18*(2), 215-231.

Besley, J. C., Dudo, A. D., Yuan, S., and Ghannam, N. A. (2016). Qualitative interviews with science communication trainers about communication objectives and goals. *Science Communication*, *38*(3), 356-381.

Bhattacharjee, Y. (2010). NSF board draws flak for dropping evolution from indicators. *Science, 328*(5975), 150-151.

Bidwell, D., Dietz, T., and Scavia, D. (2013). Fostering knowledge networks for climate adaptation. *Nature Climate Change*, *3*, 610-611.

Binder, A. R. (2010). Routes to attention or shortcuts to apathy? Exploring domain-specific communication pathways and their implications for public perceptions of controversial science. *Science Communication*, *32*(3), 383-411.

Binder, A. R., Scheufele, D. A., Brossard, D., and Gunther, A. C. (2011). Interpersonal amplification of risk? Citizen discussions and their impact on perceptions of risks and benefits of a biological research facility. *Risk Analysis*, *31*(2), 324-334.

Binder, A. R., Scheufele, D. A., and Brossard, D. (2012). Misguided science policy? The pitfalls of using public meetings as surrogate gauges of public opinion. *The Scientist*, April 10. Available: http://the-scientist.com/2012/04/10/opinion-misguided-science-policy [November 30, 2016].

Binder, A. R., Hillback, E. D., and Brossard, D. (2016). Conflict or caveats? How media portrayals of scientific uncertainty influence perceptions of new technologies. *Risk Analysis, 36*(4), 831-846.

Blank, J. M., and Shaw, D. (2015). Does partisanship shape attitudes toward science and public policy? The case for ideology and religion. *Annals of the American Academy of Political and Social Science, 658*(1), 18-35.

Bleich, S., Blendon, R., and Adams, A. (2007). Trust in scientific experts on obesity: Implications for awareness and behavior change. *Obesity*, *15*(8), 2145-2156.

Bliuc, A. M., McGarty, C., Thomas, E. F., Lala, G., Berndsen, M., and Misajon, R. (2015). Public division about climate change rooted in conflicting socio-political identities. *Nature Climate Change*, *5*(3), 226-229.

Boczkowski, P. J., and Mitchelstein, E. (2013). *The News Gap: When the Information Preferences of the Media and the Public Diverge*. Cambridge, MA: MIT Press.

Bolsen, T., and Druckman, J. N. (2015). Counteracting the politicization of science. *Journal of Communication, 65*(5), 745-769.

Bostrom, A. (2008). Lead is like mercury: Risk comparisons, analogies and mental models. *Journal of Risk Research*, *11*(1-2), 99-117.

Bostrom, A., Böhm, G., and O'Connor, R. E. (2013). Targeting and tailoring climate change communications. *Wiley Interdisciplinary Reviews: Climate Change*, *4*(5), 447-455.

Boutron, I., Altman, D. G., Hopewell, S., Vera-Badillo, F., Tannock, I., and Ravaud, P. (2014). Impact of spin in the abstracts of articles reporting results of randomized controlled trials in the field of cancer: The SPIIN randomized controlled trial. *Journal of Clinical Oncology*, *32*(36), 4120-4126.

Braman, D., Kahan, D. M., Jenkins-Smith, H. C., Tarantola, T., and Silva, C. L. (2012). Geoengineering and the science communication environment: A cross-cultural experiment. Available: http://scholarship.law.gwu.edu/faculty_publications/199 [November 30, 2016].

Brewer, P. R., and Ley, B. L. (2013). Whose science do you believe? Explaining trust in sources of scientific information about the environment. *Science Communication*, *35*(1), 115-137.

Brewer, N. T., Chapman, G. B., Gibbons, F. X., Gerrard, M., McCaul, K. D., and Weinstein, N. D. (2007). Meta-analysis of the relationship between risk perception and health behavior: The example of vaccination. *Health Psychology*, *26*(2), 136.

Brewer, N. T., Hall, M. G., Noar, S. M., Parada, H., Stein-Seroussi, A., Bach, L. E., Hanley, S., and Ribisl, K. M. (2016). Effect of pictorial cigarette pack warnings on changes in smoking behavior: A randomized clinical trial. *JAMA Internal Medicine, 176*(7), 905-912.

Brossard, D. (2012). A brave new world: Challenges and opportunities for communicating about biotechnology in new information environments. In M.-D. Weitze, A. Puehler, W. M. Heckl, B. Müller-Röber, O. Renn, P. Weingart, and G. Wess (Eds.), *Biotechnologie-Kommunikation: Kontroversen, Analysen, Aktivitäten* (pp. 427-445). Heidelberg, Germany: Springer.

Brossard, D. (2013). New media landscapes and the science information consumer. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14096-14101.

Brossard, D. (2016). *Science and Social Media*. Presentation at the 2nd meeting of the Committee on the Science of Science Communication: A Research Agenda, Washington, DC, February 25. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_171456.pdf [November 30, 2016].

Brossard, D., and Nisbet, M. C. (2007). Deference to scientific authority among a low information public: Understanding U.S. opinion on agricultural biotechnology. *International Journal of Public Opinion Research*, *19*(1), 24-52.

Brossard, D., and Scheufele, D. A. (2013). Science, new media, and the public. *Science*, *339*(6115), 40-41.

Brossard, D., Lewenstein, B., and Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099-1121.

Brown, P. (1992). Popular epidemiology and toxic waste contamination: Lay and professional ways of knowing. *Journal of Health and Social Behavior*, *33*(3), 267-281.

Brownell, K. D., and Warner, K. E. (2009). The perils of ignoring history: Big Tobacco played dirty and millions died. How similar is Big Food?. *Milbank Quarterly*, *87*(1), 259-294.

Brownson, R. C., Colditz, G. A., and Proctor, E. K. (2012). *Dissemination and Implementation Research in Health: Translating Science to Practice*. New York: Oxford University Press.

Bruine de Bruin, W., and Bostrom, A. (2013). Assessing what to address in science communication. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14062-14068.

Bruine de Bruin, W., and Wong-Parodi, G. (2014). The role of initial affective impressions in responses to educational communications: The case of carbon capture and sequestration (CCS). *Journal of Experimental Psychology: Applied, 20*(2)*,* 126-135.

Bruine de Bruin, W., Parker, A. M., and Fischhoff, B. (2007). Individual differences in adult decision-making competence. *Journal of Personality and Social Psychology, 92*(5), 938-956.

Bryk, A. S., Gomez, L. M., and Grunow, A. (2011). Getting ideas into action: Building networked improvement communities in education. In M. Hallinan (Ed.), *Frontiers in Sociology of Education* (pp. 127-162). Dordrecht, The Netherlands: Springer Publishing.

Budescu, D. V., Broomell, S., and Por, H. H. (2009). Improving communication of uncertainty in the reports of the Intergovernmental Panel on Climate Change. *Psychological Science*, *20*(3), 299-308.

Budescu, D. V., Por, H. H., and Broomell, S. B. (2012). Effective communication of uncertainty in the IPCC reports. *Climatic Change*, *113*(2), 181-200.

Budescu, D. V., Por, H. H., Broomell, S. B., and Smithson, M. (2014). The interpretation of IPCC probabilistic statements around the world. *Nature Climate Change*, *4*(6), 508-512.

Byrne, S., and Hart, P. S. (2009). The boomerang effect: A synthesis of findings and a preliminary theoretical framework. *Annals of the International Communication Association*, *33*(1), 3-37.

Cacciatore, M. A., Binder, A. R., Scheufele, D. A., and Shaw, B. R. (2012). Public attitudes toward biofuels: Effects of knowledge, political partisanship, and media use. *Politics and the Life Sciences, 31*(1), 36-51.

Cacciatore, M. A., Scheufele, D. A., and Corley, E. A. (2014). Another (methodological) look at knowledge gaps and the Internet's potential for closing them. *Public Understanding of Science*, *23*(4), 376-394.

Cacciatore, M. A., Scheufele, D. A., and Iyengar, S. (2016). The end of framing as we know it…and the future of media effects. *Mass Communication and Society*, *19*(1), 7-23.

Cappella, J. N., and Jamieson, K. H. (1997). *Spiral of Cynicism: The Press and the Public Good*. New York: Oxford University Press.

Carnevale, J. J., Inbar, Y., and Lerner, J. S. (2011). Individual differences in need for cognition and decision-making competence among leaders. *Personality and Individual Differences*, *51*(3), 274-278.

Chang, V. Y., Arora, V. M., Lev-Ari, S., D'Arcy, M., and Keysar, B. (2010). Interns overestimate the effectiveness of their hand-off communication. *Pediatrics*, *125*(3), 491-496.

Chapman, G. B., and Liu, J. (2009). Numeracy, frequency, and Bayesian reasoning. *Judgment and Decision Making*, *4*(1), 34-40.

Chi, M. T. H., Feltovich, P., and Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*(2), 121-152.

Chowdhury, P. D., Haque, C. E., and Driedger, S. M. (2012). Public versus expert knowledge and perception of climate change-induced heat wave risk: A modified mental model approach. *Journal of Risk Research*, *15*(2), 149-168.

Christakis, N. A., and Fowler, J. H. (2013). Social contagion theory: Examining dynamic social networks and human behavior. *Statistics in Medicine*, *32*(4), 556-577.

Chryssochoidis, G., Strada, A., and Krystallis, A. (2009). Public trust in institutions and information sources regarding risk management and communication: Towards integrating extant knowledge. *Journal of Risk Research*, *12*(2), 137-185.

Coburn, C. E., and Penuel, W. R. (2016). Research-practice partnerships in education outcomes, dynamics, and open questions. *Educational Researcher*, *45*(1), 48-54.

Cohen-Vogel, L. Tichnor-Wagner, A., Allen, D. Harrrison, C., Kainz, K., Rose Socol, A., and Wang, Q. (2015). Implementing educational innovations at scale: Transforming researchers into continuous improvement scientists. *Educational Policy*, *29*(2), 257-277.

Coleman, R., Thorson, E., and Wilkins, L. (2011). Testing the effect of framing and sourcing in health news stories. *Journal of Health Communication*, *16*(9), 941-954.

Colquitt, J. A., and Rodell, J. B. (2011). Justice, trust, and trustworthiness: A longitudinal analysis integrating three theoretical perspectives. *Academy of Management Journal, 54*(6), 1183-1206.

Contractor, N., and DeChurch, L. (2014). Integrating social networks and human motives to achieve social influence at scale. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 4), 13650-13657.

Cook, T. E. (1996). Afterword: Political values and production values. *Political Communication, 13*(4), 469-481.

Cook, J. (2016). Countering climate science denial and communicating scientific consensus. *Oxford Research Encyclopedia of Climate Science*. Available: http://climatescience.oxfordre.com/view/10.1093/acrefore/9780190228620.001.0001/acrefore-9780190228620-e-314 [November 30, 2016]

Cook, J., and Lewandowsky, S. (2011). *The Debunking Handbook*. St. Lucia, Australia: University of Queensland.

Corley, E. A., and Scheufele, D. A. (2010). Outreach gone wrong? When we talk nano to the public, we are leaving behind key audiences. *The Scientist*, *24*(1), 22.

Corley, E. A., Kim, Y., and Scheufele, D. A. (2012). Public challenges of nanotechnology regulation. *Jurimetrics: The Journal of Law, Science and Technology*, *52*(3), 371-381.

Corner, A., and Pidgeon, N. (2010). Geoengineering the climate: The social and ethical implications. *Environment: Science and Policy for Sustainable Development*, *52*(1), 24-37.

Corner, A., Whitmarsh, L., and Xenias, D. (2012). Uncertainty, scepticism and attitudes towards climate change: Biased assimilation and attitude polarisation. *Climatic Change*, *114*(3), 463-478.

Critchley, C. R. (2008). Public opinion and trust in scientists: The role of the research context, and the perceived motivation of stem cell researchers. *Public Understanding of Science*, *17*(3), 309-327.

Cvetkovich, G., Siegrist, M., Murray, R., and Tragesser, S. (2002). New information and social trust: Asymmetry and perseverance of attributions about hazard managers. *Risk Analysis*, *22*(2), 359-367.

Dahlstrom, M. F. (2014). Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 4), 13614-13620.

Dalrymple, K. E., Shaw, B. R., and Brossard, D. (2013). Following the leader: Using opinion leaders in environmental strategic communication. *Society & Natural Resources*, *26*(12), 1438-1453.

Dalrymple, K. E., Young, R., and Tully, M. (2016). “Facts, not fear”: Negotiating uncertainty on social media during the 2014 Ebola crisis. *Science Communication*, *38*(4), 442-467.

Davies, T., and Gangadharan, S. P. (Eds.) (2009). *Online Deliberation: Design, Research, and Practice*. Chicago, IL: University of Chicago Press.

Delli Carpini, M. X. D., Cook, F. L., and Jacobs, L. R. (2004). Public deliberation, discursive participation, and citizen engagement: A review of the empirical literature. *Annual Review of Political Science*, *7*, 315-344.

Del Vicario, M., Bessib, A. Zollo, F., Petroni, F., Scala, A., Caldarelli, G., Stanley, H. E., and Quattrociocchi, W. (2016). The spreading of misinformation online. *Proceedings of the National Academy of Sciences of the United States of America, 113*(3), 554-559.
Dewey, J. (1927). *The Public and Its Problems*. New York: Henry Holt and Company.
Dieckmann, N. F., Slovic, P., and Peters, E. (2009). The use of narrative evidence and explicit likelihood by decisionmakers varying in numeracy. *Risk Analysis*, *29*(10), 1473-1488.
Dieckmann, N. F., Johnson, B. B., Gregory, R., Mayorga, M., Han, P. K., and Slovic, P. (2015). Public perceptions of expert disagreement: Bias and incompetence or a complex and random world?. *Public Understanding of Science* [online].
Dieckmann, N. F., Gregory, R., Peters, E., and Hartman, R. (in press). Seeing what you want to see: How imprecise uncertainty ranges enhance motivated cognition. *Risk Analysis*.
Dierking, L. D., and Falk, J. H. (2016). 2020 Vision: Envisioning a new generation of STEM learning research. *Cultural Studies of Science Education*, *11*(1), 1-10.
Dietz, T. (2013a). Bringing values and deliberation to science communication. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14081-14087.
Dietz, T. (2013b). Epistemology, ontology, and the practice of structural human ecology. In T. Dietz and A. K. Jorgenson (Eds.), *Structural Human Ecology: Essays in Risk, Energy, and Sustainability* (pp. 31-52). Pullman, WA: WSU Press.
Dietz, T. (2015). Environmental values. In T. Brosch and D. Sander (Eds.), *Oxford Handbook of Values* (pp. 329-349). Oxford, UK: Oxford University Press.
Dietz, T., and Rycroft, R. W. (1987). *The Risk Professionals*. New York: Russell Sage Foundation.
Dietz, T., Stern, P. C., and Rycroft, R. W. (1989). Definitions of conflict and the legitimation of resources: The case of environmental risk. *Sociological Forum, 4*(1), 47-70.
Dietz, T., Dan, A., and Shwom, R. (2007). Support for climate change policy: Social psychological and social structural influences. *Rural Sociology*, *72*(2), 185-214.
Ding, D., Maibach, E. W., Zhao, X., Roser-Renouf, C., and Leiserowitz, A. (2011). Support for climate policy and societal action are linked to perceptions about scientific agreement. *Nature Climate Change*, *1*(9), 462-466.
Dixon, G. N., and Clarke, C. E. (2013). Heightening uncertainty around certain science media coverage, false balance, and the autism-vaccine controversy. *Science Communication*, *35*(3), 358-382.
Dobbins, M., Robeson, P., Ciliska, D., Hanna, S., Cameron, R., O'Mara, L., DeCorby, K., and Mercer, S. (2009). A description of a knowledge broker role implemented as part of a randomized controlled trial evaluating three knowledge translation strategies. *Implementation Science*, *4*(1), 1.
Downs, J. S., Murray, P. J., Bruine de Bruin, W., White, J. P., Palmgren, C., and Fischhoff, B. (2004). Interactive video behavioral intervention to reduce adolescent females' STD risk: A randomized controlled trial. *Social Science and Medicine, 59*(8), 1561-1572.
Downs, J. S., Bruine de Bruin, W., and Fischhoff, B. (2008). Parents' vaccination comprehension and decisions. *Vaccine*, *26*(12), 1595-1607.
Druckman, J. N. (2015). Communicating policy-relevant science. *PS: Political Science & Politics*, *48*(Special Issue 1), 58-69.
Dunlap, R. E., and Jacques, P. J. (2013). Climate change denial books and conservative think tanks: Exploring the connection. *American Behavioral Scientist*, *57*(6), 699-731.

Dunlap, R. E., and McCright, A. M. (2010). Climate change denial: Sources, actors and strategies. In C. Lever-Tracy (Ed.), *Handbook of Climate Change and Society* (pp. 240-259). Abingdon, UK: Routledge.

Dunwoody, S. (2014). Science journalism. In M. Bucchi and B. Trench (Eds.), *Handbook of Public Communication of Science and Technology* (pp. 15-26). New York: Routledge.

Dunwoody, S., Brossard, D., and Dudo, A. (2009). Socialization or rewards? Predicting U.S. scientist-media interactions. *Journalism & Mass Communication Quarterly*, *86*(2), 299-314.

Earle, T. C. (2010). Trust in risk management: A model-based review of empirical research. *Risk Analysis*, *30*(4), 541-574.

Earle, T. C., and Siegrist, M. (2008). On the relation between trust and fairness in environmental risk management. *Risk Analysis*, *28*(5), 1395-1414.

Ellsberg, D. (1961). Risk, ambiguity, and the Savage axioms. *The Quarterly Journal of Economics*, *75*(4), 643-669.

Entwistle, V. A., France, E. F., Wyke, S., Jepson, R., Hunt, K., Ziebland, S., and Thompson, A. (2011). How information about other people's personal experiences can help with healthcare decision-making: A qualitative study. *Patient Education and Counseling*, *85*(3), e291-e298.

Epstein, S. (1995). The construction of lay expertise: AIDS activism and the forging of credibility in the reform of clinical trials. *Science, Technology and Human Values*, *20*(4), 408-437.

Evans, A. T., Peters, E., Strasser, A. A., Emery, L. F., Sheerin, K. M., and Romer, D. (2015). Graphic warning labels elicit affective and thoughtful responses from smokers: Results of a randomized clinical trial. *PLoS One*, *10*(12), e0142879.

Eveland, W. P., and Cooper, K. E. (2013). An integrated model of communication influence on beliefs. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14088-14095.

Eveland, Jr., W. P., and Scheufele, D. A. (2000). Connecting news media use with gaps in knowledge and participation. *Political Communication*, *17*(3), 215-237.

Eysenbach, G., and Köhler, C. (2002). How do consumers search for and appraise health information on the world wide web? Qualitative study using focus groups, usability tests, and in-depth interviews. *British Medical Journal, 324*(337), 573-577.

Fahy, D., and Nisbet, M. C. (2011). The science journalist online: Shifting roles and emerging practices. *Journalism*, *12*(7), 778-793.

Farrell, J. (2016). Corporate funding and ideological polarization about climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(1), 92-97.

Farrelly, M. C., Nonnemaker, J., Davis, K. C., and Hussin, A. (2009). The influence of the national truth® campaign on smoking initiation. *American Journal of Preventive Medicine*, *36*(5), 379-384.

Fazio, L. K., Brashier, N. M., Payne, B. K., and Marsh, E. J. (2015). Knowledge does not protect against illusory truth. *Journal of Experimental Psychology: General*, *144*(5), 993.

Festinger, L., and Carlsmith, J. M. (1959). Cognitive consequences of forced compliance. *The Journal of Abnormal and Social Psychology*, *58*(2), 203.

Finucane, M. L., Alhakami, A., Slovic, P., and Johnson, S. M. (2000). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making*, *13*(1), 1.

Fischhoff, B. (1995). Risk perception and communication unplugged: Twenty years of process. *Risk Analysis*, *15*(2), 137-145.

Fischhoff, B. (2012). Communicating uncertainty fulfilling the duty to inform. *Issues in Science and Technology*, *28*(4), 63-70.

Fischhoff, B. (2013). The sciences of science communication. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14033-14039.

Fischhoff, B., and Davis, A. L. (2014). Communicating scientific uncertainty. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 4), 13664-13671.

Fischhoff, B., and Kadvany, J. (2011). *Risk: A Very Short Introduction*. New York: Oxford University Press.

Fischhoff, B., and Scheufele, D. A. (2013). The science of science communication. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14031-14032.

Fischhoff, B., and Scheufele, D. A. (2014). The science of science communication II. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 4), 13583-13584.

Fiske, S. T., Cuddy, A. J., and Glick, P. (2007). Universal dimensions of social cognition: Warmth and competence. *Trends in Cognitive Sciences*, *11*(2), 77-83.

Fiske, S. T., and Dupree, C. (2014). Gaining trust as well as respect in communicating to motivated audiences about science topics. *Proceedings of the National Academy of Sciences of the United States of America, 111*(Suppl. 4), 13593-13597.

Fowler, E. F., and Gollust, S. E. (2015). The content and effect of politicized health controversies. *The ANNALS of the American Academy of Political and Social Science, 658*(1), 155-171.

Flynn, J., Slovic, P., and Mertz, C. K. (1994). Gender, race, and perception of environmental health risks. *Risk Analysis*, *14*(6), 1101-1108.

Frank, K., Chen, I. C., Lee, Y., Kalafatis, S., Chen, T., Lo, Y. J., and Lemos, M. C. (2012). Network location and policy-oriented behavior: An analysis of two-mode networks of coauthored documents concerning climate change in the great lakes region. *Policy Studies Journal*, *40*(3), 492-515.

Freimuth, V. S., Quinn, S. C., Thomas, S. B., Cole, G., Zook, E., and Duncan, T. (2001). African Americans' views on research and the Tuskegee Syphilis Study. *Social Science and Medicine*, *52*(5), 797-808.

Freudenburg, W. R., Gramling, R., and Davidson, D. J. (2008). Scientific Certainty Argumentation Methods (SCAMs): Science and the politics of doubt. *Sociological Inquiry*, *78*(1), 2-38. Available: http://sciencepolicy.colorado.edu/students/envs_4800/freudenberg_2008.pdf [November 30, 2016].

Frewer, L. J., and Salter, B. (2007). Societal trust in risk analysis: Implications for the interface of risk assessment and risk management. In M. Siegrist, T. C. Earle, and H. Gutscher (Eds.), *Trust in Cooperative Risk Management: Uncertainty in Scepticism in the Public Mind* (pp. 143-158). Sterling, VA: Earthscan.

Frewer, L. J., Miles, S., Brennan, M., Kuznesof, S., Ness, M., and Ritson, C. (2002). Public preferences for informed choice under conditions of risk uncertainty. *Public Understanding of Science*, *11*(4), 363-372.

Funtowicz, S. O., and Ravetz, J. R. (1992). Three types of risk assessment and the emergence of post-normal science. In S. Krimsky and D. Golding (Eds.), *Social Theories of Risk* (pp. 251-274). Westport, CT: Praeger.

Gallagher, K. M., and Updegraff, J. A. (2012). Health message framing effects on attitudes, intentions, and behavior: A meta-analytic review. *Annals of Behavioral Medicine*, *43*(1), 101-116.

Gaskell, G., Allum, N., Bauer, M., Durant, J., Allansdottir, A., Bonfadelli, H., Boy, D., de Cheveigné, S., Fjaestad, B., Gutteling, J. M., Hampel, J., Jelsøe, E., Jesuino, J. C., Kohring, M., Kronberger, N., Midden, C., Nielsen, T. H., Przestalski, A., Rusanen, T., Sakellaris, G., Torgersen, H., Twardowski, T., and Wagner, W. (2000). Biotechnology and the European public. *Nature Biotechnology*, *18*(9), 935-938.

Gauchat, G. (2011). The cultural authority of science: Public trust and acceptance of organized science. *Public Understanding of Science*, *20*(6), 751-770.

Gauchat, G. (2012). Politicization of science in the public sphere a study of public trust in the United States, 1974 to 2010. *American Sociological Review*, *77*(2), 167-187.

Gelman, A., and Loken, E. (2013). *The Garden of Forking Paths: Why Multiple Comparisons Can Be a Problem, Even When There is No "Fishing Expedition" or "P-Hacking" and the Research Hypothesis was Posited Ahead of Time*. Available: http://www.stat.columbia.edu/~gelman/research/unpublished/p_hacking.pdf [November 30, 2016].

Ginsburg, A., and Smith, M. S. (2016). *Do Randomized Control Trials Meet the "Gold Standard"? A Study of the Usefulness of RCTs in the What Works Clearinghouse.* Washington, DC: American Enterprise Institute.

Glasgow, R. E., and Emmons, K. M. (2007). How can we increase translation of research into practice? Types of evidence needed. *Annual Review of Public Health*, *28*, 413-433.

Goldstein, N. J., Cialdini, R. B., and Griskevicius, V. (2008). A room with a viewpoint: Using social norms to motivate environmental conservation in hotels. *Journal of Consumer Research*, *35*(3), 472-482.

Green, L. A., and Seifert, C. M. (2005). Translation of research into practice: Why we can't "just do it." *The Journal of the American Board of Family Practice*, *18*(6), 541-545.

Gregory, R., Lichtenstein, S., and Slovic, P. (1993). Valuing environmental resources: A constructive approach. *Journal of Risk and Uncertainty*, *7*(2), 177-197.

Groeneveld, P. W., Sonnad, S. S., Lee, A. K., Asch, D. A., and Shea, J. E. (2006). Racial differences in attitudes toward innovative medical technology. *Journal of General Internal Medicine, 21*(6), 559-563.

Gromet, D. M., Kunreuther, H., and Larrick, R. P. (2013). Political ideology affects energy-efficiency attitudes and choices. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(23), 9314-9319.

Grunig, J. E., Grunig, L. A., Sriramesh, K., Huang, Y. H., and Lyra, A. (1995). Models of public relations in an international setting. *Journal of Public Relations Research*, *7*(3), 163-186.

Ham, B. (2015). *Incoming AAAS CEO Rush Holt Encourages Science Policy Advocacy*. Available: https://www.aaas.org/news/incoming-aaas-ceo-rush-holt-encourages-science-policy-advocacy [November 30, 2016].

Hampton, K. N. Rainie, L., Lu, W., Dwyer, M., Shin, I., and Purcell, K. (2014). *Social Media and the "Spiral of Silence."* Washington, DC: Pew Research Center. Available:

http://www.pewinternet.org/2014/08/26/social-media-and-the-spiral-of-silence [November 30, 2016].

Han, P. K., Klein, W. M., Lehman, T., Killam, B., Massett, H., and Freedman, A. N. (2011a). Communication of uncertainty regarding individualized cancer risk estimates effects and influential factors. *Medical Decision Making*, *31*(2), 354-366.

Han, P. K., Klein, W. M., and Arora, N. K. (2011b). Varieties of uncertainty in health care a conceptual taxonomy. *Medical Decision Making*, *31*(6), 828-838.

Hart, P. S. (2010). One or many? The influence of episodic and thematic climate change frames on policy preferences and individual behavior change. *Science Communication, 33*(1), 28-51.

Hart, P. S. (2013). The role of numeracy in moderating the influence of statistics in climate change messages. *Public Understanding of Science*, *22*(7), 785-798.

Hart, P. S., and Nisbet, N.C. (2012). Boomerang effects in science communication: How motivated reasoning and identity cues amplify opinion polarization about climate mitigation policies. *Communication Research*, *39*(6), 701-723.

Haustein, S., Peters, I., Sugimoto, C. R., Thelwall, M., and Larivière, V. (2014). Tweeting biomedicine: An analysis of tweets and citations in the biomedical literature. *Journal of the Association for Information Science and Technology, 65*(4), 656-669.

Henry, A. D. (2011). Ideology, power, and the structure of policy networks. *Policy Studies Journal*, *39*(3), 361-383.

Henry, A. D., and Dietz, T. (2011). Information, networks, and the complexity of trust in commons governance. *International Journal of the Commons*, *5*(2).

Henry, A. D., and Vollan, B. (2014). Networks and the challenge of sustainable development. *Annual Review of Environment and Resources*, *39*, 583-610.

Henry, A.D., Lubell, M., and McCoy, M. (2011). Belief systems and social capital as drivers of policy network structure: The case of California regional planning. *Journal of Public Administration Research and Theory*, *21*(3), 419-444.

Hine, D. W., Phillips, W. J., Cooksey, R., Reser, J. P., Nunn, P., Marks, A. D., Loi, N. M., and Watt, S. E. (2016). Preaching to different choirs: How to motivate dismissive, uncommitted, and alarmed audiences to adapt to climate change?. *Global Environmental Change*, *36*, 1-11.

Hmielowski, J. D., Feldman, L., Myers, T. A., Lieserowitz, A., and Maibach, E. (2014). An attack on science? Media use, trust in scientists, and perception of global warming. *Public Understanding of Science, 23*(7), 866-883.

Ho, S. S., Brossard, D., and Scheufele, D. A. (2008). Effects of value predispositions, mass media use, and knowledge on public attitudes toward embryonic stem cell research. *International Journal of Public Opinion Research*, *20*(2), 171-192.

Hon, L. C., and Grunig, J. E. (1999). *Guidelines for Measuring Relationships in Public Relations*. Available: http://www.shape.nato.int/resources/9/conference%202011/guidelines_measuring_relationships[1].pdf [November 30, 2016].

Hornik, R. (2002). Public health communication: Making sense of the contradictory evidence. In R. Hornik (Ed.), *Public Health Communication: Evidence for Behavior Change* (pp. 1-22). Mahwah, NJ: Lawrence Erlbaum Associates.

Hornsey, M. J., Harris, E. A., Bain, P. G., and Fielding, K. S. (2016). Meta-analyses of the determinants and outcomes of belief in climate change. *Nature Climate Change*, *6*, 622-626.

Howell, A. P., Shaw, B. R., and Alvarez, G. (2014). Bait shop owners as opinion leaders: A test of the theory of planned behavior to predict pro-environmental outreach behaviors and intentions. *Environment and Behavior*, *47*(10), 1107-1126.

Hurlstone, M. J., Lewandowsky, S., Newell, B. R., and Sewell, B. (2014). The effect of framing and normative messages in building support for climate policies. *PloS One*, *9*(12), e114335.

Ioannidis, J. P. (2005). Why most published research findings are false. *PLoS Medicine*, *2*(8), e124.

Institute of Medicine. (1994*). Adverse Events Associated with Childhood Vaccines: Evidence Bearing on Causality.* Washington, DC: National Academy Press.

Institute of Medicine. (2002). *Immunization Safety Review: Multiple Immunizations and Immune Dysfunction.* Washington, DC: The National Academies Press.

Institute of Medicine. (2010). *Bridging the Evidence Gap in Obesity Prevention: A Framework to Inform Decision Making.* Washington, DC: The National Academies Press.

Institute of Medicine. (2013). *Environmental Decisions in the Face of Uncertainty.* Washington, DC: The National Academies Press.

Institute of Medicine. (2014). Numeracy and the Affordable Care Act: Opportunities and challenges. In E. Peters, L. Meilleur, and M. K. Tompkins (Eds.), *Health Literacy and Numeracy: Workshop Summary* (Appendix A). Washington, DC: The National Academies Press.

Ioannidis, J. P. (2005). Why most published research findings are false. *PLoS Medicine*, *2*(8), e124.

Ipsos MORI Social Research Institute. (2014). *Public Attitudes to Science*. Available: https://www.ipsos-mori.com/Assets/Docs/Polls/pas-2014-main-report.pdf [November 30, 2016].

Iyengar, S. (1991). *Is Anyone Responsible?: How Television Frames Political Issues*. Chicago, IL: University of Chicago Press.

Iyengar, S. (1996). Framing responsibility for political issues. *Annals of the American Academy of Political and Social Science*, *546*, 59-70.

Iyengar, S., and Kinder, D. R. (1987). *News that Matters: Agenda-Setting and Priming in a Television Age*. Chicago, IL: University of Chicago Press.

Iyengar, S., and McGrady, J. (2007). *Media Politics: A Citizen's Guide*. New York: W. W. Norton & Company.

Jacks, J., and Devine, P. G. (2000). Attitude importance, forewarning of message content, and resistance to persuasion. *Basic and Applied Social Psychology*, *22*(1), 19-29.

Jamieson, K. H., and Hardy, B. W. (2014). Leveraging scientific credibility about Arctic sea ice trends in a polarized political environment. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 4), 13598-13605.

Jasanoff, S., Hurlbut, J. B., and Saha, K. (2015). CRISPR democracy: Gene editing and the need for inclusive deliberation. *Issues in Science and Technology*, *32*(1), 37.

Johnson, B. B., and Slovic, P. (1995). Presenting uncertainty in health risk assessment: Initial studies of its effects on risk perception and trust. *Risk Analysis*, *15*(4), 485-494.

Joslyn, S. L., and LeClerc, J. E. (2012). Uncertainty forecasts improve weather related decisions and attenuate the effects of forecast error. *Journal of Experimental Psychology: Applied*, *18*(1), 126-140.

Joslyn, S., Nemec, L., and Savelli, S. (2013). The benefits and challenges of predictive interval forecasts and verification graphics for end users. *Weather, Climate, and Society, 5*(2), 133-147.

Kahan, D. M. (2012). Ideology, motivated reasoning, and cognitive reflection: An experimental study. *Judgment and Decision Making*, *8*(4), 407-424.

Kahan, D. M. (2015). Climate-science communication and the measurement problem. *Political Psychology, 36*(Suppl. 1), 1-43.

Kahan, D. M. (2016). *The Strongest Evidence to Date...: What the van der Linden et al. (2015) Data Actually Show*. Yale Law and Economics Research Paper No. 542. New Haven, CT: Yale University, Yale Law School.

Kahan, D. M., Braman, D., Slovic, P., Gastil, J., and Cohen, G. (2009). Cultural cognition of the risks and benefits of nanotechnology. *Nature Nanotechnology*, *4*(2), 87-90.

Kahan, D. M., Braman, D., Cohen, G. L., Gastil, J., and Slovic, P. (2010). Who fears the HPV vaccine, who doesn't, and why? An experimental study of the mechanisms of cultural cognition. *Law and Human Behavior*, *34*(6), 501-516.

Kahneman, D. (2011). *Thinking, Fast and Slow*. New York: Macmillan Publishers.

Kanouse, D. E., Schlesinger, M., Shaller, D., Martino, S. C., and Rybowski, L. (2016). How patient comments affect consumers' use of physician performance measures. *Medical Care*, *54*, 24-31.

Kaplan, L. (2000). Public participation in nuclear facility decisions: Lessons from Hanford. In D. L. Kleinman (Ed.), *Science, Technology and Democracy* (pp. 67-83). Albany, NY: State University of New York Press.

Kaplan, S., and Garrick, B. J. (1981). On the quantitative definition of risk. *Risk Analysis*, *1*(1), 11-27.

Karpowitz, C. F., Mendelberg, T., and Shaker, L. (2012). Gender inequality in deliberative participation. *American Political Science Review*, *106*(3), 533-547.

Keller, C., Siegrist, M., and Gutscher, H. (2006). The role of the affect and availability heuristics in risk communication. *Risk Analysis*, *26*(3), 631-639.

Keohane, R. O., Lane, M., and Oppenheimer, M. (2014). The ethics of scientific communication under uncertainty. *Politics, Philosophy & Economics*, *13*(4), 343-368.

Kepplinger, H. M. (1992). Artificial horizons: How the press presented and how the population received technology in Germany from 1965-1986. In S. Rothman (Ed.), *The Mass Media in Liberal Democratic Societies* (pp. 147-176). New York: Peragon.

Kepplinger, H. M. (1995). Individual and institutional impacts upon press coverage of sciences: The case of nuclear power and genetic engineering in Germany. In M. Bauer (Ed.), *Resistance to New Technology: Nuclear Power, Information Technology, and Biotechnology* (pp. 357-377). New York: Cambridge University Press.

Kim, S., Scheufele, D. A., and Shanahan, J. E. (2002). Agenda-setting, priming, framing and second-levels in local politics. *Journalism and Mass Communication Quarterly*, *79*(1), 7-25.

Kinchy, A., Jalbert, K., and Lyons, J. (2014). What is volunteer water monitoring good for? Fracking and the plural logics of participatory science. *Political Power and Social Theory*, *27*(2), 259-289.

Kingdon, J. W. (1995). *Agendas, Alternatives, and Public Policies* (2nd Edition). Boston, MA: Little, Brown and Company.

Kothari, A., MacLean, L., Edwards, N., and Hobbs, A. (2011). Indicators at the interface: Managing policymaker-researcher collaboration. *Knowledge Management Research and Practice*, *9*(3), 203-214.

Kotler, P. T., and Keller, K. L. (2015). *Marketing Management* (15th Edition). Uttar Pradesh, India: Pearson India Education Services.

Kraft, P. W., Lodge, M., and Taber, C. S. (2015). Why people "don't trust the evidence" motivated reasoning and scientific beliefs. *The ANNALS of the American Academy of Political and Social Science*, *658*(1), 121-133.

Kümpel, A. S., Karnowski, V., and Keyling, T. (2015). News sharing in social media: A review of current research on news sharing users, content, and networks. *Social Media+ Society*, *1*(2), 2056305115610141.

Ladwig, P., Anderson, A. A., Brossard, D., Scheufele, D. A., and Shaw, B. (2010). Narrowing the nano discourse? *Materials Today*, *13*(5), 52-54.

Lang, J. T., and Hallman, W. K. (2005). Who does the public trust? The case of genetically modified food in the United States. *Risk Analysis*, *25*(5), 1241-1252.

Lavis, J. N. (2006). Research, public policymaking, and knowledge-translation processes: Canadian efforts to build bridges. *Journal of Continuing Education in the Health Professions*, *26*(1), 37-45.

Lazer, D. (2015). The rise of the social algorithm. *Science*, *348*(6239), 1090-1091.

Lazrus, H., Morss, R. E., Demuth, J. L., Lazo, J. K., and Bostrom, A. (2016). "Know what to do if you encounter a flash flood": Mental models analysis for improving flash flood risk communication and public decision making. *Risk Analysis*, *36*(2), 411-427.

LeClerc, J., and Joslyn, S. (2012). Odds ratio forecasts increase precautionary action for extreme weather events. *Weather, Climate, and Society*, *4*(4), 263-270.

Lefebvre, R. C. (2013). *Social Marketing and Social Change: Strategies and Tools for Improving Health, Well-Being, and the Environment*. Hoboken, NJ: John Wiley & Sons.

Leiserowitz, A., Maibach, E., Roser-Renouf, C., and Feinberg, G. (2013). *How Americans Communicate about Global Warming in April 2013*. New Haven, CT: Yale Project on Climate Change Communication. Available: http://environment.yale.edu/climate-communication-OFF/files/Communication-April-2013.pdf [November 30, 2016].

Leiserowitz, A., Maibach, E., Roser-Renouf, C., Feinberg, G., and Rosenthal, S. (2014). *Americans' Actions to Limit Global Warming in November 2013*. New Haven, CT: Yale Project on Climate Change Communication. Available: http://environment.yale.edu/climate-communication-OFF/files/Behavior-November-2013.pdf [November 30, 2016].

Leith, P., Haward, M., Rees, C., and Ogier, E. (2016). Success and evolution of a boundary organization. *Science, Technology and Human Values*, *41*(3), 375-401.

Lemos, M. C., Kirchhoff, C. J., Kalafatis, S. E., Scavia, D., and Rood, R. B. (2014). Moving climate information off the shelf: Boundary chains and the role of RISAs as adaptive organizations. *Weather, Climate, and Society*, *6*(2), 273-285.

Leshner, A. I. (2003). Public engagement with science. *Science, 299*(5609), 977.

Lewandowsky, S., Ecker, U. K., Seifert, C. M., Schwarz, N., and Cook, J. (2012). Misinformation and its correction continued influence and successful debiasing. *Psychological Science in the Public Interest*, *13*(3), 106-131.

Liang, X., Su, L. Y. F., Yeo, S. K., Scheufele, D. A., Brossard, D., Xenos, M., Nealey, P., and Corley, E. A. (2014). Building buzz (scientists) communicating science in new media environments. *Journalism and Mass Communication Quarterly* [online].
Lodge, M., and Taber, C. S. (2013). *The Rationalizing Voter*. New York: Cambridge University Press.
Löfstedt, R. E. (2003). Science communication and the Swedish acrylamide " alarm." *Journal of Health Communication*, *8*(5), 407-432.
Lord, C. G., Ross, L., and Lepper, M. R. (1979). Biased assimilation and attitude polarization: The effects of prior theories on subsequently considered evidence. *Journal of Personality and Social Psychology*, *37*(11), 2098-2109.
Lubchenco, J. (1998). Entering the century of the environment: A new social contract for science. *Science*, *279*(5350), 491-497.
Lubienski, C., Scott, J. T., and DeBray, E. (2014). The politics of research production, promotion, and utilization in educational policy. *Educational Policy, 28*(2), 131-144.
Lupia, A. (2002). Deliberation disconnected: What it takes to improve civic competence. *Law and Contemporary Problems*, *65*(3), 133-150.
Lupia, A. (2013). Communicating science in politicized environments. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14048-14054.
Lupia, A., Krupnikov, Y., and Levine, A. S. (2012). Beyond facts and norms: How psychological transparency threatens and restores deliberation's legitimating potential. *Southern California Law Review*, *86*, 459.
Maibach, E. W., Nisbet, M., Baldwin, P., Akerlof, K., and Diao, G. (2010). Reframing climate change as a public health issue: An exploratory study of public reactions. *BMC Public Health*, *10*(1), 1.
Maibach, E. W., Leiserowitz, A., Roser-Renouf, C., and Mertz, C. K. (2011). Identifying like-minded audiences for global warming public engagement campaigns: An audience segmentation analysis and tool development. *PLoS One*, *6*(3), e17571.
Mares, M. L. (1996). The role of source confusions in television's cultivation of social reality judgments. *Human Communication Research*, *23*(2), 278-297.
Markowitz, E. M., Slovic, P., Västfjäll, D., and Hodges, S.D. (2013). Compassion fade and the challenge of environmental conservation. *Judgment and Decision Making, 8*(4), 397-406.
Matei, S., and Ball-Rokeach, S. (2003). The Internet in the communication infrastructure of urban residential communities: Macro- or mesolinkage? *Journal of Communication, 53*(4), 642-657.
McComas, K. A., and Besley, J. C. (2011). Fairness and nanotechnology concern. *Risk Analysis, 31*(11), 1749-1761.
McComas, K., and Shanahan, J. (1999). Telling stories about global climate change measuring the impact of narratives on issue cycles. *Communication Research*, *26*(1), 30-57.
McComas, K. A., Tuite, L. S., Waks, L., and Sherman, L. A. (2007). Predicting satisfaction and outcome acceptance with advisory committee meetings: The role of procedural justice. *Journal of Applied Social Psychology, 37*(5), 905-927.
McCombs, M. (2004). *Setting the Agenda: The Mass Media and Public Opinion*. Cambridge, UK: Polity Press.
McCright, A. M. (2000). Challenging global warming as a social problem: An analysis of the conservative movement's counter-claims. *Social Problems*, *47*(4), 499-522.

McCright, A. M., and Dunlap, R. E. (2003). Defeating Kyoto: The conservative movement's impact on U.S. climate change policy. *Social Problems, 50*(3), 348-373.
McCright, A. M., and Dunlap, R. E. (2010). Anti-reflexivity the American conservative movement's success in undermining climate science and policy. *Theory, Culture & Society*, *27*(2-3), 100-133.
McCright, A. M., Dunlap, R. E., and Xiao, C. (2013a). Perceived scientific agreement and support for government action on climate change in the USA. *Climatic Change, 119*(2).
McCright, A. M., Dentzman, K., Charters, M., and Dietz, T. (2013b). The influence of political ideology on trust in science. *Environmental Research Letters, 8*(4).
McCright, A. M., Charters, M., Dentzman, K., and Dietz, T. (2015). Examining the effectiveness of climate change frames in the face of a climate change denial counterframe. *Topics in Cognitive Science, 81*(1).
McCright, A. M., Marquart-Pyatt, S. M., Shwom, R. L., Brechin, S. R., and Allen, S. (2016). Ideology, capitalism, and climate: Explaining public views about climate change in the United States. *Energy Research and Social Science*, *21*, 180-189.
McCuin, J. L., Hayhoe, K., and Hayhoe, D. (2014). Comparing the effects of traditional vs. misconceptions-based instruction on student understanding of the greenhouse effect. *Journal of Geoscience Education*, *62*(3), 445-459.
McFadden, B. R., and Lusk, J. L. (2016). What consumers don't know about genetically modified food, and how that affects beliefs. *The FASEB Journal*, *30*(9), 3091-3096.
McKeever, B. W., McKeever, R., Holton, A. E., and Li, J. Y. (2016). Silent majority: Childhood vaccinations and antecedents to communicative action. *Mass Communication and Society*, *19*(4), 1-23.
Mendelberg, T., Karpowitz, C. F., and Oliphant, J. B. (2014). Gender inequality in deliberation: Unpacking the black box of interaction. *Perspectives on Politics*, *12*(1), 18-44.
Merkle, D. M. (1996). The polls—review: The national issues convention deliberative poll. *Public Opinion Quarterly*, *60*(4), 588-619.
Michaels, D. M. (2006). Manufactured uncertainty: Protecting public health in the age of contested science and product defense. *Annals of the New York Academy of Sciences, 1076*(1), 149-162.
Michaels, D. M. (2008). *Doubt is Their Product: How Industry's Assault on Science Threatens Your Health*. New York: Oxford University Press.
Michaels, D. M., and Monforton, C. (2005). Manufacturing uncertainty: Contested science and the protection of the public's health and environment. *American Journal of Public Health*, *95*(Suppl. 1), S39-S48.
Milkman, K. L., and Berger, J. (2014). The science of sharing and the sharing of science. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 4), 13642-13649.
Miller, J. D., Pardo, R., and Niwa, F. (1997). *Public Perceptions of Science and Technology: A Comparative Study of the European Union, the United Status, Japan, and Canada*. Chicago, IL: Chicago Academy of Sciences.
Mitchell, A., Gottfried, J., Barthel, M., and Shearer, E. (2016). *The Modern News Consumer: News Attitudes and Practices in the Digital Era*. Washington, DC: Pew Research Center. Available: http:// http://www.journalism.org/2016/07/07/the-modern-news-consumer/ [November 30, 2016].

Mnookin, S. (2012). *The Panic Virus: The True Story Behind the Vaccine-Autism Controversy*. New York: Simon and Schuster.

Morgan, M. G., Cantor, R., Clark, W. C., Fisher, A., Jacoby, H. D., Janetos, A. C., Kinzig, A. P. Melillo, J., Street, R. B., and Wilbanks, T. (2005). Learning from the U.S. National Assessment of Climate Change Impacts. *Environmental Science and Technology*, *39*(23), 9023-9032.

Morrison, S. (2013). Hard numbers: Weird science. *Columbia Journalism Review.* Available: http://www.cjr.org/currents/hard_numbers_jf2013.php [November 30, 2016].

Morss, R. E., Demuth, J. L., Bostrom, A., Lazo, J. K., and Lazrus, H. (2015). Flash flood risks and warning decisions: A mental models study of forecasters, public officials, and media broadcasters in Boulder, Colorado. *Risk Analysis*, *35*(11), 2009-2028.

Moser, S. C. (2014). Communicating adaptation to climate change: The art and science of public engagement when climate change comes home. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(3), 337-358.

Munro, G. D., and Ditto, P. H. (1997). Biased assimilation, attitude polarization, and affect in reactions to stereotype-relevant scientific information. *Personality and Social Psychology Bulletin*, *23*(6), 636-653.

Munro, G. D., Ditto, P. H., Lockhart, L. K., Fagerlin, A., Gready, M., and Peterson, E. (2002). Biased assimilation of sociopolitical arguments: Evaluating the 1996 U.S. presidential debate. *Basic and Applied Social Psychology*, *24*(1), 15-26.

Myers, T. A., Maibach, E., Peters, E., and Leiserowitz, A. (2015). Simple messages help set the record straight about scientific agreement on human-caused climate change: The results of two experiments. *PLoS One*, *10*(3), e0120985.

Nan, X., Dahlstrom, M. F., Richards, A., and Rangarajan, S. (2015). Influence of evidence type and narrative type on HPV risk perception and intention to obtain the HPV vaccine. *Health Communication*, *30*(3), 301-308.

National Academies of Sciences. (2014). *The Science of Science Communication II: Summary of a Colloquium*. Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2016a). *Effective Chemistry Communication in Informal Environments*. Division on Earth and Life Studies, Division of Behavioral and Social Sciences and Education, Board on Chemical Sciences and Technology, Board on Science Education, Committee on Communicating Chemistry in Informal Settings. Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2016b). *Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values*. Committee on Gene Drive Research in Non-Human Organisms: Recommendations for Responsible Conduct, Board on Life Sciences, Division on Earth and Life Studies. Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2016c). *Science Literacy: Concepts, Contexts, and Consequences*. C. E. Snow and K. A. Dibner (Eds.), Committee on Science Literacy and Public Perception of Science, Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (1996). *Understanding Risk: Informing Decisions in a Democratic Society*. P. C. Stern and H. V. Fineberg (Eds.), Committee on Risk Characterization, Board on Environmental Change and Society, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2006). *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts*. Division on Earth and Life Studies, Board on Atmospheric Sciences and Climate, Committee on Estimating and Communicating Uncertainty in Weather and Climate Forecasts. Washington, DC: The National Academies Press.

National Research Council. (2007). *Analysis of Global Change Assessments: Lessons Learned*. Committee on Analysis of Global Change Assessments, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies. Washington, DC: The National Academies Press.

National Research Council. (2008). *Public Participation in Environmental Assessment and Decision Making.* Panel on Public Participation in Environmental Assessment and Decision Making, T. Dietz and P. C. Stern (Eds.), Committee on the Human Dimensions of Global Change, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*. P. Bell, B. Lewenstein, A. W. Shouse, and M. A. Feder (Eds.), Division of Behavioral and Social Sciences and Education, Board on Science Education, Center for Education, Committee on Learning Science in Informal Environments. Washington, DC: The National Academies Press.

National Research Council. (2012). *Using Science as Evidence in Public Policy*. K. Prewitt, T. A. Schwandt, and M. L. Straf (Eds.), Committee on the Use of Social Science Knowledge in Public Policy, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2014). *Review of EPA's Integrated Risk Information System (IRIS) Process*. Committee to Review the IRIS Process, Board on Environmental Studies and Toxicology, Division on Earth and Life Studies. Washington, DC: The National Academies Press.

National Science Board. (2014). Chapter 7: Science and technology: Public attitudes and public understanding. *Science and Engineering Indicators 2014.* Arlington, VA: National Science Foundation.

National Science Board. (2016a). Chapter 7: Science and technology: Public attitudes and understanding. *Science and Engineering Indicators 2016*. Arlington, VA: National Science Foundation. Available: https://www.nsf.gov/statistics/2016/nsb20161/uploads/1/10/chapter-7.pdf [November 8, 2016].

National Science Board. (2016b). *Science and Engineering Indicators 2016*. NSB-2016-1. Arlington, VA: National Science Foundation.

National Science Foundation. (2015). *Social, Behavioral, and Economic Sciences Perspectives on Robust and Reliable Science*. Report of the Subcommittee on Replicability in Science Advisory Committee to the National Science Foundation Directorate for Social, Behavioral, and Economic Sciences. Arlington, VA: National Science Foundation.

Neeley, E., Goldman, E., Smith, B., Baron, B., and Sunu, S. (2015). *GRADSCICOMM Report and Recommendations: Mapping the Pathways to Integrate Science Communication*

Training into STEM Graduate Education. Available: http://compassblogs.org/gradscicomm [November 30, 2106].

Nelkin, D. (1992). *Controversy: Politics of Technical Decisions*. Newbury Park, CA: SAGE Publications.

Nelkin, D. (1996). An uneasy relationship: The tensions between medicine and the media. *Lancet, 347*, 1600-1603.

Nickerson, R. S. (1999). How we know—and sometimes misjudge—what others know: Imputing one's own knowledge to others. *Psychological Bulletin*, *125*(6), 737.

Niebert, K., and Gropengießer, H. (2014). Understanding the greenhouse effect by embodiment—analysing and using students' and scientists' conceptual resources. *International Journal of Science Education*, *36*(2), 277-303.

Niederdeppe, J., Shapiro, M. A., Kim, H. K., Bartolo, D., and Porticella, N. (2014). Narrative persuasion, causality, complex integration, and support for obesity policy. *Health Communication*, *29*(5), 431-444.

Nisbet, M. C. (2005). The competition for worldviews: Values, information, and public support for stem cell research. *International Journal of Public Opinion Research*, *17*(1), 90-112.

Nisbet, M. C. (2011). Public opinion and participation. In J. S. Dryzek, R. B. Norgaard, and D. Schlosberg (Eds.), *The Oxford Handbook of Climate Change and Society* (p. 355). New York: Oxford University Press.

Nisbet, M. C. (2014). Engaging the public in science policy controversies: Insights from the U.S. climate change debate. In M. Bucchi and B. Trench (Eds.), *Handbook of Public Communication of Science and Technology* (2nd Edition) (pp. 173-185). New York: Routledge.

Nisbet, M. C., and Feldman, L. (2011). The social psychology of political communication. In D. Hook, B. Franks, and M. Bauer (Eds.), *The Social Psychology of Communication* (pp. 284-299). London, UK: Palgrave Macmillan.

Nisbet, M. C., and Huge, M. (2006). Attention cycles and frames in the plant biotechnology debate managing power and participation through the press/policy connection. *The Harvard International Journal of Press/Politics*, *11*(2), 3-40.

Nisbet, M. C., and Huge, M. (2007). Where do science debates come from? Understanding attention cycles and framing. In D. Brossard, J. Shanahan, and T. C. Nesbitt (Eds.), *The Media, the Public and Agricultural Biotechnology* (pp. 193-230). Wallingford, UK: CAB International.

Nisbet, M. C., and Kotcher, J. E. (2009). A two-step flow of influence? Opinion-leader campaigns on climate change. *Science Communication, 30*(3), 328-354.

Nisbet, M. C., and Markowitz, E. (2016). *Science Communication Research: Bridging Theory and Practice*. Washington, DC: American Association for the Advancement of Science.

Nisbet, M. C., and Scheufele, D. A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany*, *96*(10), 1767-1778.

Nisbet, M. C., Scheufele, D. A., Shanahan, J., Moy, P. Brossard, D., and Lewenstein, B. V. (2002). Knowledge, reservations, or promise? A media effects model for public perceptions of science and technology. *Communication Research*, *29*(5), 584-608.

Nisbet, M. C., Brossard, D., and Kroepsch, A. (2003). Framing science the stem cell controversy in an age of press/politics. *The International Journal of Press/Politics*, *8*(2), 36-70.

Nisbet, E. C., Hart, P. S., Myers, T., and Ellithorpe, M. (2013). Attitude change in competitive framing environments? Open-/closed-mindedness, framing effects, and climate change. *Journal of Communication*, *63*(4), 766-785.

Nisbet, E. C., Cooper, K. E., and Garrett, R. K. (2015). The partisan brain how dissonant science messages lead conservatives and liberals to (dis) trust science. *The ANNALS of the American Academy of Political and Social Science*, *658*(1), 36-66.

Noel, H., and Nyhan, B. (2011). The "unfriending" problem: The consequences of homophily in friendship retention for causal estimates of social influence. *Social Networks*, *33*(3), 211-218.

Noelle-Neumann, E. (1993). *The Spiral of Silence: Public Opinion, Our Social Skin* (2nd Edition). Chicago, IL: University of Chicago Press.

Nyhan, B., Reifler, J., and Ubel, P. A. (2013). The hazards of correcting myths about health care reform. *Medical Care*, *51*(2), 127-132.

Nyhan, B., Reifler, J., Richey, S., and Freed, G. L. (2014). Effective messages in vaccine promotion: A randomized trial. *Pediatrics*, *133*(4), e835-e842.

O'Keefe, D. J., and Jensen, J. D. (2007). The relative persuasiveness of gain-framed loss-framed messages for encouraging disease prevention behaviors: A meta-analytic review. *Journal of Health Communication*, *12*(7), 623-644.

O'Keefe, D. J., and Nan, X. (2012). The relative persuasiveness of gain-and loss-framed messages for promoting vaccination: A meta-analytic review. *Health Communication*, *27*(8), 776-783.

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science*, *349*(6251).

Oreskes, N., and Conway, E. M. (2011). *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. New York: Bloomsbury Publishing USA.

Oskamp, S., and Schultz, P. W. (2005). *Attitudes and Opinions*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Pariser, E. (2012). *The Filter Bubble: How the New Personalized Web is Changing What We Read and How We Think.* New York: Penguin Books.

Patterson, T. E. (1994). *Out of Order: An Incisive and Boldly Original Critique of the News Media's Domination of America's Political Process*. New York: Vintage.

Payne, C.R, Shwom, R., and Heaton, S. (2015). Public participation and norm formation for risky technology: Adaptive governance of solar-radiation management. *Climate Law, 5*(2-4):210-251.

Pearson, A. R., and Schuldt, J. P. (2015). Bridging climate communication divides beyond the partisan gap. *Science Communication*, *37*(6), 805-812.

Peters, J. W. (2010). At Yahoo, using searches to steer news coverage. *The New York Times,* July 5. p. B1. Available: http://www.nytimes.com/2010/07/05/business/media/05yahoo.html [November 30, 2016].

Peters, E. (2012a). Beyond comprehension: The role of numeracy in judgments and decisions. *Current Directions in Psychological Science*, *21*(1), 31-35.

Peters, H. P. (2012b). Scientific sources and the mass media: Forms and consequences of medialization. In *The Sciences' Media Connection–Public Communication and its Repercussions* (pp. 217-239). Dordrecht, The Netherlands: Springer.

Peters, H. P. (2013). Gap between science and media revisited: Scientists as public communicators. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl. 3), 14102-14109.
Peters, R. G., Covello, V. T., and McCallum, D. B. (1997). The determinants of trust and credibility in environmental risk communication: An empirical study. *Risk Analysis*, *17*(1), 43-54.
Peters, E., Lipkus, I., and Diefenbach, M. A. (2006). The functions of affect in health communications and in the construction of health preferences. *Journal of Communication*, *56*(Suppl. 1), S140-S162.
Peters, E., Dieckmann, N., Dixon, A., Hibbard, J. H., and Mertz, C. K. (2007). Less is more in presenting quality information to consumers. *Medical Care Research and Review*, *64*(2), 169-190.
Peters, E., Hart, P. S., Tusler, M., and Fraenkel, L. (2014). Numbers matter to informed patient choices a randomized design across age and numeracy levels. *Medical Decision Making*, *34*(4), 430-442.
Pew Research Center. (2009a). *Public Praises Science; Scientists Fault Public, Media. Scientific Achievements Less Prominent Than a Decade Ago*. Available: http://www.people-press.org/2009/07/09/public-praises-science-scientists-fault-public-media [November 8, 2016].
Pew Research Center. (2009b). *Growing Interest in Swine Flu, Many See Press Overstating Its Danger*. Available: http://www.people-press.org/2009/10/15/growing-interest-in-swine-flu-many-see-press-overstating-its-danger [November 30, 2016].
Pew Research Center. (2014). *Ebola Worries Rise, But Most Are "Fairly" Confident in Government, Hospitals to Deal with Disease*. Available: http://www.people-press.org/2014/10/21/ebola-worries-rise-but-most-are-fairly-confident-in-government-hospitals-to-deal-with-disease/ [November 30, 2016].
Pew Research Center. (2015a). *Public and Scientists' Views on Science and Society*. Available: http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society [November 30, 2016].
Pew Research Center. (2015b). *Religion and Science*. Available: http://www.pewinternet.org/2015/10/22/science-and-religion [November 30, 2016].
Pew Research Center. (2016a). *State of the News Media 2016.* Available: http://www.journalism.org/2016/06/15/newspapers-fact-sheet [November 30, 2016].
Pew Research Center. (2016b). *The Politics of Climate*. Available: http://www.pewinternet.org/2016/10/04/the-politics-of-climate [November 30, 2016].
Pielke Jr., R. A. (2007). *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge, UK: Cambridge University Press.
Politi, M. C., Han, P. K., and Col, N. F. (2007). Communicating the uncertainty of harms and benefits of medical interventions. *Medical Decision Making*, *27*(5), 681-695.
Politi, M. C., Clark, M. A., Ombao, H., Dizon, D., and Elwyn, G. (2011). Communicating uncertainty can lead to less decision satisfaction: A necessary cost of involving patients in shared decision making?. *Health Expectations*, *14*(1), 84-91.
Rabinovich, A., and Morton, T. A. (2012). Unquestioned answers or unanswered questions: Beliefs about science guide responses to uncertainty in climate change risk communication. *Risk Analysis*, *32*(6), 992-1002.

Rahn, W. M., and Transue, J. E. (1998). Social trust and value change: The decline of social capital in American youth, 1976-1995. *Political Psychology*, *19*(3), 545-565.
Ranney, M. A., Clark, D., Reinholz, D. L., and Cohen, S. (2012). Changing global warming beliefs with scientific information: Knowledge, attitudes, and RTMD (Reinforced Theistic Manifest Destiny theory). In *Proceedings of the 34th Annual Meeting of the Cognitive Science Society* (pp. 2228-2233). Austin, TX: Cognitive Science Society.
Ratner, R. K., and Riis, J. (2014). Communicating science-based recommendations with memorable and actionable guidelines. *Proceedings of the National Academy of Sciences of the United States of America, 111*(Suppl. 4), 13634-13641.
Renn, O. (2008). *Risk Governance: Coping with Uncertainty in a Complex World*. London, UK: Earthscan.
Renn, O., and Levine, D. (1991). Credibility and trust in risk communication. In *Communicating Risks to the Public* (pp. 175-217). Dordrecht, The Netherlands: Springer.
Reyna, V. F., and Brainerd, C. J. (1991). Fuzzy trace theory and framing effects in choice: Gist extraction, truncation, and conversion. *Journal of Behavioral Decision Making*, *4*(4), 249-262.
Reyna, V. F., Nelson, W. L., Han, P. K., and Dieckmann, N. F. (2009). How numeracy influences risk comprehension and medical decision making. *Psychological Bulletin*, *135*(6), 943-973.
Rice, R. E., and Foote, D. R. (2001). *Public Communication Campaigns*. Thousand Oaks, CA: SAGE Publications.
Roduta-Roberts, M., Reid, G., Schroeder, M., and Norris, S. P. (2011). Causal or spurious? The relationship of knowledge and attitudes to trust in science and technology. *Public Understanding of Science*, *22*(5), 624-641.
Rogers, E. M., Dearing, J. W., and Chang, S. (1991). AIDS in the 1980s: The agenda-setting process for a public issue. *Journalism and Communication Monographs*, *126*.
Rosa, E. A. (1998). Metatheoretical foundations for post-normal risk. *Journal of Risk Research*, *1*(1), 15-44.
Rosa, E. A., Tuler, S. P., Fischhoff, B., Webler, T., Friedman, S. M., Sclove, R. E., Shrader-Frechette, K., English, M. R., Kasperson, R. E., Goble, R. L., Leschine, T. M., Freudenburg, W., Chess, C., Perrow, C., Erikson, K., and Short, J. F. (2010). Nuclear waste: knowledge waste?. *Science*, *329*(5993), 762-763.
Rosa, E., Renn, O., and McCright, A. (2013). *The Risk Society Revisited*. Philadelphia, PA: Temple University Press.
Roser-Renouf, C., Maibach, E. W., Leiserowitz, A., and Zhao, X. (2014). The genesis of climate change activism: From key beliefs to political action. *Climatic Change, 125*(2), 163-178.
Rothman, A. J., and Salovey, P. (1997). Shaping perceptions to motivate healthy behavior: The role of message framing. *Psychological Bulletin*, *121*(1), 3.
Rowland, F. S. (1993). President's lecture: The need for scientific communication with the public. *Science, 260*(5114), 1571-1576.
Runge, K. K., Yeo, S. K., Cacciatore, M., Scheufele, D. A., Brossard, D., Xenos, M., Anderson, A., Choi, D.-H., Kim, J., Li, N., Liang, X., Stubbings, M., and Su, L. Y.-F. (2013). Tweeting nano: How public discourses about nanotechnology develop in social media environments. *Journal of Nanoparticle Research*, *15*(1), 1-11.
Ryan, C. L., and Bauman, K. (2016). *Educational Attainment in the United States: 2015*. Available:

https://www.census.gov/content/dam/Census/library/publications/2016/demo/p20-578.pdf [November 30, 2016].

Sarewitz, D. (2015). Science can't solve it. *Nature, 522*(7557), 413-414.

Satterfield, T. A., Mertz, C. K., and Slovic, P. (2004). Discrimination, vulnerability, and justice in the face of risk. *Risk Analysis*, *24*(1), 115-129.

Savelli, S., and Joslyn, S. (2013). The advantages of predictive interval forecasts for non□expert users and the impact of visualizations. *Applied Cognitive Psychology*, *27*(4), 527-541.

Scheufele, D. A. (1999). Framing as a theory of media effects. *Journal of Communication*, *49*(1), 103-122.

Scheufele, D. A. (2000). Agenda-setting, priming, and framing revisited: Another look at cognitive effects of political communication. *Mass Communication and Society*, *3*(2-3), 297-316.

Scheufele, D. A. (2007). Nano does not have a marketing problem…yet. *Nano Today, 2*(5), 48.

Scheufele, D. A. (2012). *Modern Citizenship or Policy Dead End? Evaluating the Need for Public Participation in Science Policy Making, and Why Public Meetings May Not Be the Answer*. Politics and Public Policy Research Paper Series #R□34. Available: http://shorensteincenter.org/wp-content/uploads/2012/03/r34_scheufele.pdf [November 30, 2016].

Scheufele, D. A. (2013). Communicating science in social settings. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Suppl. 3), 14040-14047.

Scheufele, D. A. (2014). Science communication as political communication. *Proceedings of the National Academy of Sciences of the United States of America, 111*(Suppl. 4), 13585-13592.

Scheufele, D. A., and Lewenstein, B. V. (2005). The public and nanotechnology: How citizens make sense of emerging technologies. *Journal of Nanoparticle Research*, *7*(6), 659-667.

Scheufele, D. A., and Nisbet, M. C. (2002). Being a citizen online new opportunities and dead ends. *The Harvard International Journal of Press/Politics*, *7*(3), 55-75.

Scheufele, D. A., and Nisbet, M. C. (2012). Commentary: Online news and the demise of political disagreement. In C.T. Salmon (Ed.), *Communication Yearbook* (pp. 36-45). Newbury Park, CA: Sage.

Scheufele, B. T., and Scheufele, D. A. (2010). Of spreading activation, applicability, and schemas. In P. D'Angelo and J. A. Kuypers (Eds.), *Doing News Framing Analysis: Empirical and Theoretical Perspectives* (pp. 110-134). New York: Routledge.

Scheufele, D. A., Corley, E. A., Shih, T.-J., Dalrymple, K. E., and Ho, S. S. (2009). Religious beliefs and public attitudes to nanotechnology in Europe and the U.S. *Nature Nanotechnology, 4*(2), 91-94.

Schuldt, J. P., and Pearson, A. R. (2016). The role of race and ethnicity in climate change polarization: Evidence from a U.S. national survey experiment. *Climatic Change*, *136*(3-4), 495-505.

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., and Griskevicius, V. (2007). The constructive, destructive, and reconstructive power of social norms. *Psychological Science*, *18*(5), 429-434.

Segev, E., and Baram-Tsabari, A. (2010). Seeking science information online: Data mining Google to better understand the roles of the media and the education system. *Public Understanding of Science, 21*(7), 813-829.

Shafer, M. S. (2012). Online communication on climate change and climate politics: A literature review. *WIREs: Climate Change*, *3*(6), 527-543.

Shaffer V. A., and Zikmund-Fisher, B. (2012). All stories are not alike: Purpose-, content-, and valence-based taxonomy of patient narratives in decision aids. *Medical Decision Making, 33*(1), 4-13.

Shalizi, C. R., and Thomas, A. C. (2011). Homophily and contagion are generically confounded in observational social network studies. *Sociological Methods and Research*, *40*(2), 211-239.

Sherif, M. (Ed.). (1967). *Social Interaction: Process and Products*. New Brunswick, NJ: Transaction Publishers.

Shrum, L. J. (2007). Social cognition and cultivation. In D. R. Roskos-Ewoldsen and J. L. Monahan (Eds.), *Communication and Social Cognition: Theories and Methods* (pp. 245-272). Mahwah, NJ: Lawrence Erlbaum Associates.

Siegrist, M., Cvetkovich, G., and Roth, C. (2000). Salient value similarity, social trust, and risk/benefit perception. *Risk Analysis, 20*(3), 353-362.

Sinayev, A., and Peters, E. (2015). The impact of cognitive reflection versus calculation in decision making. *Frontiers in Psychology*, *6*, 532.

Sinayev, A., Peters, E., Tusler, M., and Fraenkel, L. (2015). Presenting numeric information with percentages and descriptive risk labels: A randomized trial. *Medical Decision Making*, *35*(8), 937-947.

Singhal, A., and Rogers, E. (2012). *Entertainment-Education: A Communication Strategy for Social Change*. New York: Routledge.

Skurnik, I., Yoon, C., Park, D. C., and Schwarz, N. (2005). How warnings about false claims become recommendations. *Journal of Consumer Research*, *31*(4), 713-724.

Slater, M. D. (1996). Theory and method in health audience segmentation. *Journal of Health Communication*, *1*(3), 267-284.

Slater, M. D., Hayes, A. F., Reineke, J. B., Long, M., and Bettinghaus, E. P. (2009). Newspaper coverage of cancer prevention: Multilevel evidence for knowledge-gap effects. *Journal of Communication*, *59*(3), 514-533.

Slavin, R. E. (2006). Translating research into widespread practice: The case of success for all. In M. A. Constas and R. J. Sternberg (Eds.), *Translating Theory and Research into Educational Practice: Developments in Content Domains, Large Scale Reform, and Intellectual Capacity* (pp. 113-126). New York: Routledge.

Slimak, M. W., and Dietz, T. (2006). Personal values, beliefs and ecological risk perception. *Risk Analysis*, *26*(6), 1689-1705.

Slovic, P. (1987). Perception of risk. *Science 236*(4799), 280-285.

Slovic, P. (1999). Trust, emotion, and sex. *Risk Analysis, 19*(4), 689-701.

Slovic, P. (2000). *The Perception of Risk*. London, UK: Earthscan.

Slovic, P. (2016). Understanding perceived risk: 1978-2015. *Environment: Science and Policy for Sustainable Development*, *58*(1), 25-29.

Slovic, P., Finucane, M. L., Peters, E., and MacGregor, D. G. (2004). Risk as analysis and risk as feelings: Some thoughts about affect, reason, risk, and rationality. *Risk Analysis*, *24*(2), 311-322.

Soll, J., Keeney, R., and Larrick, R. (2012). Consumer misunderstanding of credit card use, payments. *Journal of Public Policy and Marketing, 32*(1), 66-81.

Spartz, J. T., Rickenbach, M., and Shaw, B. R. (2015a). Public perceptions of bioenergy and land use change: Comparing narrative frames of agriculture and forestry. *Biomass and Bioenergy*, *75*, 1-10.

Spartz, J. T., Su, L. Y. F., Griffin, R., Brossard, D., and Dunwoody, S. (2015b). YouTube, social norms and perceived salience of climate change in the American mind. *Environmental Communication*, 1-16.

Spence, A., and Pidgeon, N. (2010). Framing and communicating climate change: The effects of distance and outcome frame manipulations. *Global Environmental Change*, *20*(4), 656-667.

Spiegelhalter, D., Pearson, M., and Short, I. (2011). Visualizing uncertainty about the future. *Science*, *333*(6048), 1393-1400.

Steg, L., and de Groot, J. I. M. (2012). Environmental values. In S. Clayton (Ed.), *The Oxford Handbook of Environmental and Conservation Psychology* (pp. 81-92). New York: Oxford University Press.

Stephens, E. M., Edwards, T. L., and Demeritt, D. (2012). Communicating probabilistic information from climate model ensembles—lessons from numerical weather prediction. *Wiley Interdisciplinary Reviews: Climate Change*, *3*(5), 409-426.

Stewart, D. W. (Ed.). (2014). *The Handbook of Persuasion and Social Marketing.* Santa Barbara, CA: ABC-CLIO, LLC.

Sturgis, P., and Allum, N. (2004). Science in society: Re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, *13*(1), 55-74.

Su, L. Y. F., Cacciatore, M. A., Scheufele, D. A., Brossard, D., and Xenos, M. A. (2014). Inequalities in scientific understanding differentiating between factual and perceived knowledge gaps. *Science Communication*, *36*(3), 352-378.

Su, L. Y. F., Akin, H., Brossard, D., Scheufele, D. A., and Xenos, M. A. (2015). Science news consumption patterns and their implications for public understanding of science. *Journalism and Mass Communication Quarterly* [online].

Su, L. Y. F., Cacciatore, M. A., Liang, X., Brossard, D., Scheufele, D. A., and Xenos, M. A. (2016). Analyzing public sentiments online: combining human-and computer-based content analysis. *Information, Communication and Society*, *20*(3), 1-22.

Suhay, E., and Druckman, J. N. (2015). The politics of science political values and the production, communication, and reception of scientific knowledge. *The ANNALS of the American Academy of Political and Social Science*, *658*(1), 6-15.

Sullivan, T. M., McPartland, T., and Fisher, B. S. (2013). *Guidelines for Successful Researcher Practitioner Partnerships in the Criminal Justice System: Findings from the Researcher-Practitioner Partnerships Study (RPPS)*. Available: https://www.ncjrs.gov/pdffiles1/nij/grants/243918.pdf [November 30, 2016].

Sunstein, C. R. (2009). *Republic.com 2.0.* Princeton, NJ: Princeton University Press.

Taylor, A. L., Dessai, S., and Bruine de Bruin, W. (2015). Communicating uncertainty in seasonal and interannual climate forecasts in Europe. *Philosophical Transactions of the Royal Society A, 373*(2055)*,* 1-16.

Teigen, K. H., and Brun, W. (2003). Verbal probabilities: A question of frame?. *Journal of Behavioral Decision Making*, *16*(1), 53-72.

Teigen, K. H. (2014). Psychology: When very likely is not so likely. *Nature Climate Change*, *4*(6), 421-422.

Tichenor, P. J., Donohue, G. A., and Olien, C. N. (1970). Mass media flow and differential growth in knowledge. *Public Opinion Quarterly*, *34*(2), 159-170.
Tonia, T., Van Oyen, H., Berger, A., Schindler, C., and Künzli, N. (2016). If I tweet will you cite? The effect of social media exposure of articles on downloads and citations. *International Journal of Public Health, 61*(4), 513-520.
Tseng, V. (2012). Studying the use of research evidence in policy and practice. *Social Policy Report, 26*(2), 3-16.
Tversky, A., and Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*(4157), 1124-1131.
U.S. Census Bureau. (2013). *American Community Survey Demographic and Housing Estimates: 2011-2013 American Community Survey 3-Year Estimates*. Available: http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_13_3YR_DP05&prodType=table [August 6, 2016].
van der Linden, S. L., Clarke, C. E., and Maibach, E. W. (2015). Highlighting consensus among medical scientists increases public support for vaccines: Evidence from a randomized experiment. *BMC Public Health*, *15*(1), 1.
Visschers, V. H. M., and Siegrist, M. (2012). Fair play in energy policy decisions: Procedural fairness, outcome fairness and acceptance of the decision to rebuild nuclear power plants. *Energy Policy, 46*, 292-300.
Visschers, V. H. M., & Siegrist, M. (2013). How a nuclear power plant accident influences acceptance of nuclear power: Results of a longitudinal study before and after the Fukushima disaster. *Risk Analysis, 33*(2), 333-347. doi:10.1111/j.1539-6924.2012.01861.x.
Viswanath, K. (2006). Public communications and its role in reducing and eliminating health disparities. In G. E. Thomson, F. Mitchell, and M. B. Williams (Eds.), *Examining the Health Disparities Research Plan of the National Institutes of Health: Unfinished Business* (pp. 215-253). Washington, DC: The National Academies Press.
Volk, R. J., Jibaja-Weiss, M. L., Hawley, S. T., Kneuper, S., Spann, S. J., Miles, B. J., and Hyman, D. J. (2008). Entertainment education for prostate cancer screening: A randomized trial among primary care patients with low health literacy. *Patient Education and Counseling*, *73*(3), 482-489.
Vosniadou, S., and Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*(4), 535-585.
Wakefield, M., Flay, B., Nichter, M., and Giovino, G. (2003). Effects of anti-smoking advertising on youth smoking: a review. *Journal of Health Communication*, *8*(3), 229-247.
Wakefield, M. A., Loken, B., and Hornik, R. C. (2010). Use of mass media campaigns to change health behaviour. *The Lancet*, *376*(9748), 1261-1271.
Wallack, L. (1993). *Media Advocacy and Public Health: Power for Prevention*. Newbury Park, CA: SAGE Publications.
Wallsten, T. S. (1990). Measuring vague uncertainties and understanding their use in decision making. In G. M. von Furstenberg (Ed.), *Acting under Uncertainty: Multidisciplinary Conceptions* (pp. 377-398). Dordrecht, The Netherlands: Springer.
Watts, D. J., and Dodds, P. S. (2007). Influentials, networks, and public opinion formation. *Journal of Consumer Research, 34*(4), 441-458.

Weiss, C. H. (1988). Evaluation for decisions: Is anybody there? Does anybody care?. *Evaluation Practice*, *9*(1), 5-19.

Whitfield, S. C., Rosa, E. A., Dan, A., and Dietz, T. (2009). The future of nuclear power: Value orientations and risk perception. *Risk Analysis*, *29*(3), 425-437.

Winterbottom, A., and Bekker, H. L. (2009). Should patient stories be used in decision aids?. In A. Edwards and G. Elwyn (Eds.), *Shared Decision-making in Health Care: Achieving Evidence-based Patient Choice* (pp. 217-222). New York: Oxford University Press.

Winterbottom, A., Bekker, H. L., Conner, M., and Mooney, A. (2008). Does narrative information bias individuals' decision making? *Social Science & Medicine*, *67*(12), 2079-2088.

Witzling, L., Shaw, B., and Seiler, D. (2016). Segmenting boaters based on level of transience: Outreach and policy implications for the prevention of aquatic invasive species. *Biological Invasions*, *18*(12), 3635-3646.

Wolfe, M., Jones, B. D., and Baumgartner, F. R. (2013). A failure to communicate: Agenda setting in media and policy studies. *Political Communication, 30*(2), 175-192.

Wynne, B. (1989). Sheep farming after Chernobyl: A case study in communicating scientific information. *Environment Magazine, 31*(2), 10-15, 33-39.

Yankelovich, D. (1991). *Coming to Public Judgment: Making Democracy Work in a Complex World*. Syracuse, NY: Syracuse University Press.

Yearley, S. (2005). *Making Sense of Science*. London, UK: SAGE Publications.

Yeo, S. K., Xenos, M. A., Brossard, D., and Scheufele, D. A. (2015). Selecting our own science: How communication contexts and individual traits shape information seeking. *The ANNALS of the American Academy of Political and Social Science*, *658*(1), 172-191.

Zikmund-Fisher, B. J. (2013). The right tool is what they need, not what we have: A taxonomy of appropriate levels of precision in patient risk communication. *Medical Care Research and Review, 70*(Suppl. 1):37S-49S.

APPENDIX A
Committee on the Science of Science Communication: A Research Agenda

Biographical Sketches of Committee Members and Staff

Alan Leshner (Chair) (NAM) is chief executive officer, emeritus, of the American Association for the Advancement of Science (AAAS) and former executive publisher of the journal *Science*. Before this position, Dr. Leshner was director of the National Institute on Drug Abuse at the National Institutes of Health. He also served as deputy director and acting director of the National Institute of Mental Health and in several roles at the National Science Foundation. Before joining the government, Dr. Leshner was professor of psychology at Bucknell University. He is an elected fellow of AAAS, the American Academy of Arts and Sciences, the National Academy of Public Administration, and many other professional societies. He is a member and served on the governing council of the National Academy of Medicine (previously the Institute of Medicine). He was appointed by President George W. Bush to the National Science Board in 2004, and then reappointed by President Obama in 2011. Dr. Leshner received Ph.D. and M.S. degrees in physiological psychology from Rutgers University and an A.B. in psychology from Franklin and Marshall College. He has been awarded seven honorary doctor of science degrees.

Dietram Scheufele (Vice Chair) is the John E. Ross professor in science communication in the Department of Life Sciences Communication at the University of Wisconsin-Madison, and Vilas Distinguished Achievement Professor at the University of Wisconsin-Madison and in the Morgridge Institute for Research. Since 2013, he has also held an honorary professorship at the Dresden University of Technology in Germany. Dr. Scheufele is a fellow of the American Association for the Advancement of Science, the International Communication Association, and the Wisconsin Academy of Sciences, Arts & Letters, and a member of the German National Academy of Science and Engineering. He has been a tenured faculty member at Cornell University, a Shorenstein fellow at Harvard University, and a visiting scholar at the Annenberg Public Policy Center of the University of Pennsylvania. He received an M.A. in journalism and mass communications and a Ph.D. in mass communications with a minor in political science from the University of Wisconsin-Madison.

Emily Backes *(associate program officer)* at the National Academies of Sciences, Engineering, and Medicine supports the Forum on Promoting Children's Cognitive, Affective, and Behavioral (C-CAB) Health and leads the Collaborative on Messaging for C-CAB Health. She has provided analytical and editorial support for studies on juvenile justice reform, forensic science, the illicit tobacco market, science literacy, and the science of science communication. Previously, she worked with the Committee on Human Rights, with responsibility for researching cases of unjustly imprisoned scientists worldwide and synthesizing scholarship on science and human rights issues. She received an M.A. and B.A. in history from the University of Missouri and is pursuing a J.D. at the University of the District of Columbia's David A. Clarke School of Law.

Ann Bostrom is Weyerhaeuser endowed professor of environmental policy at the Daniel J. Evans School of Public Policy and Governance, University of Washington. She previously served on the faculty at the Georgia Institute of Technology, 1992-2007, where she was associate dean for research at the Ivan Allen College of Liberal Arts and professor in the School of Public

Policy. Dr. Bostrom co-directed the Decision Risk and Management Science Program at the National Science Foundation, 1999-2001. Her research focuses on risk perception, communication, and management and on environmental policy and decision making under uncertainty. Dr. Bostrom serves as associate editor for the *Journal of Risk Research* and is on the editorial boards of *Risk Analysis* and *Environmental Hazards*. She is an elected fellow of the American Association for the Advancement of Science and past president and an elected fellow of the Society for Risk Analysis. She received a Ph.D. in public policy analysis from Carnegie Mellon University, an M.B.A. from Western Washington University, and a B.A. from the University of Washington.

Wändi Bruine de Bruin is university leadership chair in behavioral decision making at the Leeds University Business School, where she also serves as co-director of the Centre for Decision Research. She holds affiliations with Carnegie Mellon University, the University of Southern California, and the RAND Corporation. Her research focuses on behavioral decision making, individual differences in decision-making competence across the life span, and risk perception and communication. Dr. Bruine de Bruin is a member of the editorial boards of the *Journal of Risk Research*, the *Journal of Experimental Psychology: Applied*, the *Journal of Behavioral Decision Making*, *Medical Decision Making*, and *Psychology and Aging*. She is a member of the Scientific & Technical Committee of the International Risk Governance Council (IRGC), which provides evidence-based advice to international policy makers. She has contributed her expertise to an expert panel report on health product risk communication by the Council of Canadian Academies, as well as to several expert workshops. Dr. Bruine de Bruin received a B.Sc. and M.Sc. in psychology and cognitive psychology, respectively, from Free University Amsterdam and an M.Sc. and Ph.D. in behavioral decision theory and psychology from Carnegie Mellon University.

Karen Cook (NAS) is Ray Lyman Wilbur professor of sociology, director of the Institute for Research in the Social Sciences, and vice-provost for faculty development and diversity at Stanford University. She conducts research on social exchange networks, power and influence dynamics, intergroup relations, negotiation strategies, social justice, and trust in social relations. Her research underscores the importance of trust in facilitating exchange relationships and of networks in creating social capital—for example, in physician-patient interaction and its effect on health outcomes. Dr. Cook has edited and co-edited a number of books in the Russell Sage Foundation Trust Series, is co-author of *Cooperation without Trust?*, and co-edited *Sociological Perspectives on Social Psychology*. In 1996, she was elected to the American Academy of Arts and Sciences and in 2007 to the National Academy of Sciences. In 2004 she received the Cooley Mead Award of the American Sociological Association's Social Psychology Section for career contributions to social psychology. Dr. Cook received her M.A. and Ph.D. in sociology from Stanford University.

Thomas Dietz is professor of sociology and environmental science and policy at Michigan State University (MSU). He is also co-director of the Great Lakes Integrated Sciences and Assessment Center. At MSU he was founding director of the Environmental Science and Policy Program and associate dean in the Colleges of Social Science, Agriculture and Natural Resources, and Natural Science. His current research examines the human driving forces of environmental change, environmental values, and the interplay between science and democracy in environmental issues.

Dr. Dietz is a fellow of the American Association for the Advancement of Science and is former president of the Society for Human Ecology. He has received the Sustainability Science Award of the Ecological Society of America; the Distinguished Contribution Award and Outstanding Publication Award of the American Sociological Association's Section on Environment, Technology and Society; and the Gerald R. Young Book Award from the Society for Human Ecology. Dr. Dietz holds a Ph.D. in ecology from the University of California, Davis, and a bachelor of general studies degree from Kent State University.

William K. Hallman is professor and chair of the Department of Human Ecology and a member of the graduate faculty of the Department of Nutritional Sciences and of the Bloustein School of Planning and Public Policy at Rutgers, the State University of New Jersey. During the fall of 2016, he was a distinguished visiting fellow at the Annenberg Public Policy Center of the University of Pennsylvania. His research examines public perceptions of controversial issues concerning food, health, and the environment. A member of several advisory panels and committees, Dr. Hallman recently served as chair of the Risk Communication Advisory Committee of the U.S. Food and Drug Administration, and co-authored the *Risk Communication Applied to Food Safety Handbook*, produced jointly by the Food and Agriculture Organization of the United Nations and the World Health Organization. He formerly served as director of the Food Policy Institute at Rutgers. Dr. Hallman is a graduate of Juniata College in Huntingdon, Pennsylvania, and received an M.A. and Ph.D. in experimental psychology from the University of South Carolina.

Jeffrey R. Henig is professor of political science and education at Teachers College and professor of political science at Columbia University. He is a member of the National Academy of Education and a fellow of the American Education Research Association. Dr. Henig focuses on the intersection of politics and social science research. He is the author, coauthor, or co-editor of eleven books. His 2008 book, *Spin Cycle: How Research Gets Used in Policy Debates: The Case of Charter Schools,* won the American Educational Research Association's Outstanding Book Award, and two of his books have been recognized by the Urban Politics Section of the American Political Science Association as the best books on urban politics. In addition to scholarly publications, his writing on contemporary policy issues has been featured in several publications aimed at general audiences. Dr. Henig received a Ph.D. in political science from Northwestern University.

Robert Hornik is Wilbur Schramm professor of communication and health policy at the Annenberg School for Communication, University of Pennsylvania. Since 2013 he has been co-director of the Penn Tobacco Center of Regulatory Science, a first-of-its-kind regulatory science research enterprise aimed at informing the regulation of tobacco products to protect public health. Dr. Hornik led the Center of Excellence in Cancer Communication Research at the University of Pennsylvania, 2003-2014. His most recent research focuses on how Americans are affected by their exposure to information about cancer prevention, screening, and treatment; the effects of new and old media content on tobacco-related beliefs and behavior among youth and young adults; and the development and validation of methods for choosing preferred message themes for communication campaigns. Dr. Hornik has particular expertise in research methods for determining the effects of public health communication interventions and of media exposure.

He received an A.B. in international relations from Dartmouth College and an M.A. and Ph.D. in communication research from Stanford University.

Andrew Maynard is professor in the School for the Future of Innovation in Society, Arizona State University, and director of the Risk Innovation Lab, focused on public thinking and action related to risk in the context of technology innovations. His research explores the responsible development and use of emerging technologies, including nanotechnology and synthetic biology, and science communication and public engagement on these issues. He is widely published and has testified before the U.S. Congress on several occasions regarding nanotechnology policy and research needs related to nanotechnology risk. Dr. Maynard is a regular contributor to a special column of the journal *Nature Nanotechnology* and is on the editorial board of the *Journal of Responsible Innovation*. He works closely with and through conventional and new media to connect with audiences around the world on technology innovation and the science of risk. He received a B.Sc. in physics from the University of Birmingham (U.K.) and a Ph.D. in aerosol physics from the University of Cambridge (U.K.).

Matthew Nisbet is associate professor of communication studies and affiliate associate professor of public policy and urban affairs at Northeastern University. He is editor-in-chief of the journal *Environmental Communication* and a founding senior editor at ORE Climate Science. Nisbet studies the role of communication, media, and public opinion in debates over science, technology, and the environment. He is the author of more than 70 peer-reviewed studies, scholarly book chapters, and reports. Dr. Nisbet has been a visiting Shorenstein fellow at Harvard University's Kennedy School of Government, a health policy investigator at the Robert Wood Johnson Foundation, and a Google science communication fellow. In 2011, the editors of the journal *Nature* recommended his research as "essential reading for anyone with a passing interest in the climate change debate," and the *New Republic* highlighted his work as a "fascinating dissection of the shortcomings of climate activism." Dr. Nisbet's consulting experience includes analysis on behalf of the American Association for the Advancement of Science, the National Academies, the Howard Hughes Medical Institute, the Corporation for Public Broadcasting, the Centers for Disease Control and Prevention, and other public- and private-sector clients. He holds a Ph.D. and M.S. in communication from Cornell University.

Ellen M. Peters is professor of psychology and director of the Decision Sciences Collaborative at Ohio State University. Her research focuses on understanding the basic building blocks of human judgment and decision making, in particular how affective, intuitive, and deliberative processes help people make decisions in an increasingly complex world. Dr. Peters has authored more than 100 peer-reviewed manuscripts and has worked extensively with the U.S. National Cancer Institute and Food and Drug Administration (FDA) to advance the science of human decision making as it applies to health and health policy. She is former president of the Society for Judgment and Decision Making; former chair of the FDA's Risk Communication Advisory Committee; and a fellow of the American Psychological Association, Association for Psychological Science, and Society of Experimental Psychology. She has been awarded the Jane Beattie Scientific Recognition Award, a National Institutes of Health Merit Award, and two Best Paper Awards from *Risk Analysis.* Dr. Peters received a B.S. in economics and B.S.E. in systems engineering from the University of Pennsylvania and an M.S. and Ph.D. in psychology from the University of Oregon.

Holly Rhodes *(program officer)* has directed or contributed to projects of the National Academies that include the Workshop on the Early Care and Education Workforce, the Science of Family Research Dissemination project, and the consensus study that produced the report *Mathematics Learning in Early Childhood.* Prior to her work at the National Academies, she was deputy project director at RTI International for the research program on national preschool curriculum evaluation. She holds master's and doctorate degrees in education from the University of North Carolina at Chapel Hill.

Sylvia Rowe is president of SR Strategy, which facilitates science communication and policy on a broad range of global health, nutrition, food safety, and risk issues. She is also an adjunct professor at the University of Massachusetts Amherst and Tufts Friedman School of Nutrition Science and Policy. Ms. Rowe is an experienced communication practitioner with particular expertise in bringing diverse groups together around policy issues related to food, nutrition, and health. Previously, she served as president and chief executive officer of the International Food Information Council (IFIC) and IFIC Foundation. She is also a member of the International Women's Leadership Forum and the National Press Club, among other professional groups. Ms. Rowe's background in media and expertise in issues management are reflected in her professional history as a producer and on-air host of several television and radio talk shows covering social, political, and economic and consumer issues. She also previously held positions in public relations, marketing, and membership development for several diverse associations. Ms. Rowe received a bachelor's degree from Wellesley College and a master's degree from Harvard University.

Melissa Welch-Ross *(study director)* is director of special initiatives in the Division of Behavioral and Social Sciences and Education within the National Academies. She has directed activities for the National Academies on a variety of topics, including literacy education, language development, child abuse and neglect, transportation systems, and science communication. Prior to joining the National Academies she served as a special expert in research and policy at the U.S. Department of Health and Human Services. She earlier launched and directed the Early Learning and School Readiness Research Program for the National Institute of Child Health and Human Development at the National Institutes of Health. She has held faculty appointments at George Mason University and Georgia State University, where she conducted research on memory development in early childhood. She previously served as executive branch science policy fellow at the U.S. Department of Education, with sponsorship from the American Association for the Advancement of Science and Society for Research in Child Development. She was lead editor of the 2007 *Handbook on Communicating and Disseminating Behavioral Science*. She received a Ph.D. in psychology from the University of Florida.

APPENDIX B

Committee on the Science of Science Communication: A Research Agenda

AGENDA, Meeting 1

Keck Center, Room 103
500 Fifth Street NW, Washington, D.C.

December 17-18, 2015

OPEN SESSION

9:00 Statement of Task: Sponsor Perspectives

9:00 Welcome and Introductions
Alan Leshner, Committee Chair

9:05 Introduction to the Statement of Task
Alan Leshner

9:10 Elizabeth Christopherson, Rita Allen Foundation
Paul Hanle, Climate Central

9:20 Chad English, Packard Foundation

9:30 Q&A and Discussion with Committee Members
Moderator: Alan Leshner

9:45 Practitioner Perspectives

Guiding questions: What are the main challenges of communicating science for any topic; what are additional challenges of communicating science on topics that have become contentious? What are promising approaches or practices for addressing communication challenges; what is the evidence? What needs to be better understood to communicate effectively about science on important societal issues?

Moderator: Alan Leshner, Committee Chair
Each presenter will have 25 minutes (15 minutes followed by 10 minutes of Q&A), with time for general discussion.

Engaging the Public

9:45 Radiation Risk

Jerrold Bushberg, University of California, Davis School of Medicine, and National Council on Radiation Protection and Measurements

10:10 Food Safety and Nutrition
Joe Levitt, Hogan Lovells

10:35 General Discussion

Media

10:55 Cornelia Dean, New York Times, and Brown University

11:20 Richard Harris, National Public Radio

11:45 General Discussion

Supports for Engagement

12:05 Brooke Smith, COMPASS

12:30 Lunch (*served in the meeting room*)

1:30 **Perspectives from Decision Science, Political Science, and Science in Society**

Guiding questions: What are the main challenges of communicating science for any topic; what are additional challenges of communicating science on topics that have become contentious? What are promising approaches or practices for addressing communication challenges; what is the evidence? What needs to be better understood to communicate effectively about science related to important societal issues?

Moderator: Alan Leshner, Committee Chair

1:30 Baruch Fischhoff, Carnegie Mellon University
1:45 Q &A

2:00 Bruce Lewenstein, Cornell University
2:15 Q&A

2:30 Arthur (Skip) Lupia, University of Michigan
2:45 Q&A

3:00 General Discussion

3:45 **Break**
Adjourn Open Session

Committee on the Science of Science Communication: A Research Agenda
Meeting #2

February 24-25, 2016

Keck Center, Room 201
500 5th Street NW
Washington, DC 20001

Agenda

OPEN SESSION

10:15 Public Controversies Involving Science
Much of the available literature related to the communication of science on important societal issues pertains to a single issue area, such as climate change, vaccination, obesity, hydraulic fracturing, nuclear energy, genetically modified organisms, and so on. This panel is part of a larger effort of the committee to gather information across a set of controversies that have involved science in public decisions and debates. Each speaker has been asked to respond to questions below to address the charge:

- What are the main controversies and what is the role of science? What factors (i.e., psychological social, cultural, political, economic, media-related, science-related, communication-related, or other contextual factors) affect how the relevant science is understood, perceived and used (i.e., has affected decisions and other behaviors?)
- What has been learned that could apply to other controversies about (1) practices for communicating science to prevent controversy and (2) practices that are successful or not successful for communicating science in the midst of controversy?
- What are important and empirically researchable questions to inform approaches to communicating science related to controversial societal issues?

10:15 Welcome and introductions, Alan Leshner, Committee Chair
Each presentation will be followed by brief clarifying Q&A, followed by discussion
10:20 Seth Mnookin, Massachusetts Institute of Technology
10:40 Noel Brewer, University of North Carolina at Chapel Hill
11:00 Ed Maibach, George Mason University
11:20 Discussion

11:45 Lunch

Thursday, February 25, 2016
OPEN SESSION

9:05 Communicating Science for Policy Related to Contentious Societal Issues

Much has been written about communicating science for policy. A lot of theorizing, analysis, and advice have been offered, but less research is available to understand how science is communicated and used and how to communicate effectively in policy contexts to support the use of research. The purpose of this panel is to aid the committee in determining what is most important to understand through research about communicating science for policy that pertains to societal issues and decisions that are controversial in the public sphere. In particular:

- Does effective science communication matter for science policy, and if so, how does it matter?
- What are the audiences for science in the policy arena and how should communication differ across them?
- What are trusted sources of information about science for policy and what makes them trustworthy?
- What are the limits of science evidence in the policy arena?
- What are the most important challenges for communicating science related to controversial issues?
- Are there examples of successful communication of science, and examples of approaches that were not successful?
- How should approaches to communicating science differ depending on whether the issue is high in public attention and political sensitivity?

9:05 Welcome and Introductions, Alan Leshner
Each presenter will provide opening remarks followed by discussion
9:10 Rick Spinrad, NOAA
9:20 Bob Inglis, RepublicEn
9:30 Brian Baird, 4Pir2 Communications
9:40 Daniel Sarewitz, Arizona State University
9:50 Rush Holt, American Association for the Advancement of Science
10:00 Discussion

10:45 Break

11:00 Panel: Issues of Social Media and Social Networks for the Communication of Science Related to Contentious Societal Issues

Science communication through social media is increasing rapidly, and yet remains poorly understood. Over the past few years, social media platforms – blogging and Twitter in particular – have provided scientists and other communicators of science new ways of connecting with audiences, having a voice, and directly addressing controversial issues. Given the increasing accessibility, reach, and growth in the use of social media for science communication, this panel brings together researchers of social media, social networks and science communicators to discuss the following questions:

- What is known from research about uses of social media and social networks for science communication related to important societal issues?

- What is likely to be effective or not effective? What is the evidence from the research and from practitioner perspectives?
- What are the roles of social media and social networks related to controversial societal issues such as climate change, GMOs, and vaccines?
- What are important directions for research related to social media and social networks for science communication and for assessing effectiveness and societal impact?

11:05 Dominique Brossard, University of Wisconsin-Madison
11:20 Noshir Contractor, Northwestern University
11:35 Hilda Bastian, National Center for Biotechnology Information (NCBI), National Institutes of Health
11:50 Discussion

12:15 Lunch (informal discussion continues)