This article reports the principal findings and recommendations of the Research Roadmap Panel for Public Communication of Science and Technology in the Twenty-first Century. Beginning in 1998, the Space Sciences Laboratory at NASA's George C. Marshall Space Flight Center chartered a fifteen-member working group to develop a research strategy that would address the big questions in science communication academic research and identify the best practices in science and technology communication as they are being implemented in research institutions across the United States and abroad. The working group met eight times at various U.S. research institutions, invited science communicators and others to meet with them, and solicited public and other comment in preparation for this article.

Communicating the Future

Report of the Research Roadmap Panel for Public Communication of Science and Technology in the Twenty-first Century

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Beginning in 1998, the Space Sciences Laboratory (SSL) of NASA's George C. Marshall Space Flight Center (MSFC) established a blue-ribbon panel[1] of science communicators, communication researchers, Pulitzer Prize–winning journalists, and scientists to assist its efforts in public communication of NASA research. The SSL had recently reorganized to support an in-house communication function separate from the MSFC public affairs office, one aimed principally at directly communicating scientific results to lay audiences rather than channeling those messages through mass media. Senior

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researchers at the SSL hoped to have the panel review the fundamental research base that underpins public communication of science and technology, advise them on some areas of communication research that would benefit most from funding, and identify best practices in science and technology communication that MSFC/SSL might wish to adopt for its own use.

Working under a cooperative agreement with the University of Florida, which had previously conducted a communications audit and other research on MSFC's science communication enterprise, the Research Roadmap Panel for Public Communication of Science and Technology in the Twenty-first Century (dubbed the R2 group) met formally eight times from 1998 to 2000, hosted each time by various research institutions across the United States.[2] At each meeting, science communicators, journalists, scientists, and researchers were invited to attend to share their experiences in public communication with the panel. In addition, an open invitation was issued to the community of science communicators (as reflected in membership in the National Association of Science Writers and other professional organizations, or members of the working press covering science and technology in the region) to join the panel's deliberations. The meetings were open to the public, and MSFC was fully committed to open sharing of the panel's findings and recommendations.

In addition, panel members met informally at major professional meetings such as the Council for the Advancement of Science Writing's New Horizons Briefings and the annual meetings of the National Association of Science Writers and the Association for Education in Journalism and Mass Communication.

Panel Charge

The panel was charged with two very different tasks. First, to help guide future NASA investments in science communication research, the panel was asked to review the recent literature on science communication and related fields and to frame the big questions that remained to be answered by communication scholars working in science and technology communication. Second, the panel was asked to survey science communication activities at scientific research institutions in the United States and abroad for models that could be adapted for use at MSFC or other research-performing organizations.

To address the first charge, the panel commissioned a review of the recent traditional science communication literature. That review, by University of Florida associate professor and panel member Michael Weigold (2001 [this issue]), can be found in this issue of *Science Communication*. The panel commissioned a complementary review of the health communication literature from Michael Antecol, then of the Stanford Center for Research in Disease Prevention and directed panel member Robert Logan of the University of Missouri to do a cursory review of the literature from agriculture extension and report back to the group on the potential value of a complementary review of that literature. On the basis of these reviews, and in consultation with other science communication researchers, the panel outlined a series of questions that need to be addressed by future research. The panel also sponsored pilot studies in three of the most promising research areas, and two of those studies (Priest 2001 [this issue]; Tremayne and Dunwoody 2001 [this issue]) appear in this issue of *Science Communication.*

In addressing the second charge, the panel consulted widely and reviewed dozens of existing science communication efforts undertaken by universities, corporations, public relations agencies, museums, professional societies and organizations, and other science communication practitioners. In addition, the panel organized an international peer-reviewed conference to review best-practice submissions, cosponsored by the U.S. Department of Energy and the National Institute of Standards and Technology (NIST) and scheduled for 6-8 March 2002 at NIST's Gaithersburg, Maryland, campus. Entries selected as best practices were invited to develop poster presentations for the conference that will be archived on the World Wide Web and in print form. This article lays the groundwork for identification of these best practices.

The panel also commissioned a review of federal science communication activities from Bruce Lewenstein at Cornell University. That review was not complete as this issue went to press.

The Purposes of Communication

While the panel recognizes that many societal needs are fulfilled by communication about science and technology, for the purpose of this article, the panel identifies three primary purposes for the communication of scientific information by agencies and institutions. It is communication of these types that the panel addresses in its findings and conclusions:

To inform consumers, patients, and citizens about scientific activities, products, or conclusions that may be useful in improving the quality of life generally or in regard to specific problems, issues, or events. This kind of communication would include messages from the National Institutes of Health about new medical research, information from the Department of

Agriculture about the safe use of pesticides, reports from the Department of Transportation about the safety of specific vehicles, or information from the National Park Service about vacation sites and resources.

To provide information for citizens to enable them to understand, think about, and perhaps participate in the formulation of public policy on specific issues. This kind of communication might include information from the Department of Agriculture and the Food and Drug Administration about genetically modified foods, information from the Department of Energy about current energy resources and future needs, or information from NASA about the status and uses of the space station. Some of these communications may be persuasive in character, while others may involve only a presentation of research results. Some messages in this category may involve a compilation of differing views, options, and arguments.

To provide descriptions and explanations of scientific work to enhance the level of scientific or biomedical literacy in the recipient. This kind of communication is represented by the programs of museums, agency visitor centers, and Web sites to provide new information about previous and current scientific work. The numerous Web sites operated by NASA, the National Institutes of Health, the Smithsonian, and numerous agencies, universities, and professional societies provide additional examples of this kind of communication.

Principal Findings and Conclusions—Research Roadmap

In his literature review in this issue, Weigold (2001) provides a more extensive roadmap and rationale for a research agenda in science communication than is possible here. The panel endorses these recommendations.

In particular, the panel notes that as the disciplines of science communication per se and health communication have matured, many academicians have chosen one field as a specialty to the exclusion of the other. This has led to the development of two very distinct fields of endeavor that have lost much of their potential for interdisciplinary collaboration and mutual cross-fertilization.

Another related discipline with promise for informing science communication is that of agricultural communication. An early communication model, diffusion of innovations, was developed to explain the process whereby agricultural innovations diffuse through opinion leaders and early adopters to the broader population. Today, agricultural communication scholars are dealing with issues of direct relevance to science communication, including the public's acceptance of genetically modified foods.

To make the most of limited resources to support academic research in the broader field of public communication about science, health, and technology, the panel urges the research community and the funding community for these endeavors to actively seek opportunities for greater collaboration and synchronization of research.

The panel identified three research areas as being especially deserving of attention from science communication scholars and their allied colleagues:

Exploring the Relationship between Quality or Quantity of Science Communication, Adult Scientific Literacy, and Citizen Science Advocacy

The panel noted that much of current communication practice assumes that good science communication yields benefits in terms of broader citizen support for the scientific enterprise. This assumption is not supported in the literature, and in the panel's view, it is unlikely to accurately represent what is clearly a very complex communication system.

This issue is not unique to science communication. To take one example, political communication scholars dating back to the nineteenth century have decried the ignorance of voters about their political environments, politicians, issues, and events. This ignorance flourishes despite the fact that political topics receive substantially heavier coverage in the news media than does science and despite the fact that the reporters who cover politics generally are sophisticated and knowledgeable about their topic. These reporters are well rewarded and represent some of the best talent in the news industry. And, those who produce political messages are among the most skilled: politicians and their press officers often are unrivaled experts at message packaging and presentation (in stark contrast to common portrayals of scientists). In other words, in politics, the public receives a large amount of news by expert reporters interviewing the masters of sound bites. Yet, people frequently cannot name both of their senators, have no idea who the nine justices on the Supreme Court are (or even that there are nine justices), and in general claim to lack respect for elected officials and the people who cover them.

The panel notes these things to make a simple point: political ignorance flourishes in spite of heavy coverage, knowledgeable reporting, and media-savvy participants. In addition, the public's evaluation of both reporters and politicians is not especially positive. There may be some lessons and important cautions from the broader field of political communication as we address prescriptions for enhancing science communication.

Understanding the Interests and Behaviors of Publics Who Consume or Use Science and Technical Information

Similarly, much of current public communication practice is based on identifying what the public ought to know and providing that, rather than identifying what the public wants to know and finding ways to make this knowledge available and accessible (Ziman 1992). While there is a rich literature on uses of political information (see, e.g., McCombs and Shaw 1993), as well as on health information and health-behavior modification, the corresponding literature on use of scientific information per se is relatively slight.

Understanding the Ecosystem of Communication between the Research Scientist, the News Reporter or Other Communicator, and the Institutional Public Information Officer

Little is known about the role that the science public information officer (PIO) plays in brokering communication between scientists and representatives of the media and other external audiences, in part because the defined career of this individual is a very recent phenomenon. However, the panel believes that the role of the PIO is expanding rapidly, both in scope and in the number of institutions and organizations that employ him or her, and that the relationships that a PIO manages with external audiences increasingly influence the process and products of science communication.

One promising model for studying this ecosystem may be game theory. Originally developed in the 1950s, game theory models how actors choose among behavioral options as a function of the rewards and costs for such choices. It goes beyond simple stimulus-response formulations, however, because it can model the actions of two or more decisionmakers simultaneously and can develop such models based on whether the decisionmakers have full or incomplete information about their choices. Game theory has been applied productively to politics, international relations, and social relationships. It has recently become more important in public relations. Game theory may provide a useful way to study the changing dynamics in science communication because it provides a way to predict how decisionmakers will respond to changing reward-cost structures in their environments.

Principal Findings and Conclusions—Best Practices

The panel was struck overall by the general lack of intellectual rigor applied to science and technology communication activities, especially as contrasted with the very rigorous scientific environment in which this communication arises. Communication often remains an afterthought, a by-product of scientific endeavor somehow removed from the scientific process itself and often funded by a different mechanism than the scientists who perform the research. The panel firmly believes that public communication of research results is, and should be, integrated into the scientific process itself. It is not an optional activity at the conclusion of a research program. It should be amenable to the same experimental paradigms as laboratory science's.

The panel also was very concerned about the dearth of formative or evaluative research that underpins the vast majority of science and technology communication in the United States (and as far as the panel was able to determine, the rest of the world). For a data-driven enterprise, science demands very few data from communicators of science, either to craft and frame appropriate messages and message content or to evaluate the impact of messages on scientific knowledge or behavior. The best evaluation seems to occur in the context of health-behavior campaigns, where the end product is a definable set of behavioral outcomes. As a rule, this kind of evaluative framework is lacking entirely in communication programs about basic research and technology. The panel urges science communicators to undertake rigorous formative and evaluative research as part of any communication process.

One last general observation concerns the role of mass media in nurturing public understanding of science and technology. As a rule, the panel observed, mass media are a very poor tool for remedial science education. Basic understanding of science and technology is only minimally affected in adult life by consumption of media stories about scientific issues. It appears that the role of K-12 education is far more important than subsequent exposure to science communication (Friedman, Dunwoody, and Rogers 1999).

The remainder of the panel's principal findings with respect to best practices in public communication of science and technology fall under six general observations.

- Finding 1: There is no such thing as a general audience for science and technology communication; rather, there are many people with many different uses for science and technology information and many levels of understanding with which to deal.

The public is not a uniform whole but is segmented by differing interests, differing abilities, differing resources, and differing needs. This is not a new idea. In the tenth Federalist Paper, James Madison wrote that one of the strengths and protections of a democratic society is the plurality of interests found in each citizen.

The research programs of scholars such as Miller (1986) and Prewitt (1982) have helped immensely in understanding this plurality of interests among science news consumers. Among their somewhat bleak findings are the following: almost half of American adults report that they do not follow any public policy area closely (Miller 1986). Prewitt (1982) and Miller (1986) both advocate segmenting science news audiences based on their interests in science. Heavy consumers of science news are a minority of adults, but they remain important because of their prominence and importance in society.

The most recent assessment of U.S. attitudes about science and technology, the National Science Board's (NSB's) (2000b) *Science and Engineering Indicators 2000* report, found that less than 10 percent of the U.S. public can be considered "science attentive" for most issues covered by the NSB survey. Science attentives are those individuals who express a high level of interest in a particular issue, feel well-informed about that issue, and read regularly about that issue. Medical research has the largest audience, about 16 percent. Similarly, few Americans are likely to be attentive to science and technology policy issues—about 12 percent. The "interested" public—those who claim a high level of interest but do not feel well informed about a particular topic—comprises about 44 percent of the population. Miller (1986) characterized the demographics of these populations, noting that the science-attentive public is more likely than the population at large to be younger, male, better educated, and to have taken a college-level science course. Science-interested publics are older, less educated, and less likely to have had a college-level science class.

There is a wide disparity in the kinds of science and technology information generally known by the U.S. population. More than 70 percent of Americans know, for example, that oxygen comes from plants, that the continents are moving and have done so for millions of years, that light travels faster than sound, and that the Earth goes around the Sun. However, one-half or fewer of Americans know that the earliest humans did not live at the same time as dinosaurs, that it takes the Earth one year to go around the Sun, that electrons are smaller than atoms, or that antibiotics do not kill viruses (NSB 2000b).

Despite long-standing awareness of the diversity of the consuming publics for science and technology information, the panel noted that most science communication still fell into one of only two categories: peer communication aimed at fellow scientists and technologists and public communication aimed at everyone else. The literature the panel reviewed and the best practices it observed in use make very clear that there is no such thing as a one-size-fits-all public communication message for a mythical lay public. Single messages designed to reach all public audiences typically end up reaching none of them very well, especially in an information environment with a myriad of media channels (which is growing daily) from which an audience may choose what suits it.

This finding flies in the face, also, of traditional mediated communication programs, which see their principal or only focus as delivering news items up to the news media. While mediated communication has an important role to play in increasing public understanding of science and technology (and this role will continue in the foreseeable future, the panel believes), public discourse is no longer driven by a few major media players. An individual article or story placed in an individual news medium is more likely to be lost in the very crowded intellectual marketplace than it is to have a profound impact on public understanding of science.

All communication should have an intended audience, and most messages are designed to be received and used by selected individuals and groups. The prior selection of an audience is important because audiences differ in their interests and in their ability to use various kinds of information. The preparation of a one-size-fits-all message for all possible audiences and outlets is almost always ineffective and is a practice to be discouraged.

The effectiveness of communication—the accurate receipt and use of information—can be improved substantially by carefully defining intended audiences and by tailoring the level of information provided to each audience. While many federal agencies and grant-receiving institutions feel that it is necessary in a democratic society to provide all public information in a style and format accessible to adults with an upper-elementary reading level, it is important to recognize that citizens differ in interests, in their level of education and scientific literacy, and in the amount of time and effort they are willing to devote to any given subject or issue. Some individuals will prefer (and more effectively utilize) written material while other citizens may prefer and need pictures, audio, and graphic presentations.

The panel also notes in this context that extensive reliance on general-public messages seriously undermines efforts to address hard-to-reach audiences such as racial and ethnic minorities and those without Internet access.

The panel recommends that federal agencies and their grantees and contractors recognize the multifaceted nature of the public (individuals, groups, and institutions) and design communication programs appropriate to the needs of each group. This approach should mean not that some groups are inherently better served than others but that the type and level of communication is designed to address and serve the needs of each group within the public.

- Finding 2: The scientific community and managers of the science enterprise routinely fail to distinguish between understanding of science and appreciation for science- or research-performing institutions.

The panel believes that both of these goals are appropriate and laudable under the right circumstances. But far too often, the panel observed, communication programs that are intended to enhance the reputation and cachet of individual agencies, institutions, or organizations are touted as programs that increase public understanding of science. The goals of these two programs are not necessarily complementary and in fact often work at cross-purposes.

In particular, the panel notes that collaboration is essential to the process of science—professional collegiality undergirds the infrastructure of scientific research. But, institutional reputations are made and preserved by claiming credit for scientific advancements or technological achievements, and sharing of credit dilutes institutional advancement goals.

Moreover, the effective communication of the process of science (which the panel believes is equal in importance to communication about products of science if the goal is public understanding) requires an acknowledgement that scientific experiments do not always work and that this kind of failure is as instructive and valuable as experiments that yielded the expected results. But scientists working with public dollars often are reluctant to disclose research failures, leading to unrealistic public expectations about scientific progress. Such failure is generally seen as anathema to institutional advancement.

The lack of distinction between these sometimes-competing goals also leads to poor metrics of communication efficacy. While evaluation is generally poor across the board in science communication (as noted above), where metrics do exist, they are more likely to be measures of approval or support than measures of knowledge or behavior.

The panel recommends that communication campaigns in science and technology explicitly address at the outset whether the goal is public understanding or public appreciation, and design metrics appropriate for measuring the desired outcome.

- Finding 3: Science and technology communication should not be driven by the research enterprise's desires about what the public should know. Communication should be driven by a desire to meet audience needs and interests.

Scientists have an obligation to understand publics and their communication needs if communication is to be effective. Once again, the multiplicity of available media channels makes it unrealistic to expect an audience to attend to messages or communication in which it has no interest. There are no captive audiences for science and technology information.

- Finding 4: The active involvement of scientists and engineers is critical to the success of science communication.

In 1996, Neal Lane (cited in Cialdini 1997), then director of the National Science Foundation, challenged scientists by suggesting, "If you don't take it as one of your professional responsibilities to inform your fellow citizens about the importance of the science and technology enterprise, then the public support—critical to sustaining it—isn't going to be there" (p. 676). Although a direct causal relationship between communication and agency funding is doubtful, many voices overwhelmingly suggest that principles of public accountability will require researchers will be expected to describe what society has received for its investment.

Most academic research suggests that in general, scientists are interested in educating the public through the mass media, they understand that they have such an obligation (DiBella, Ferri, and Padderud 1991), and they are well aware of the possible advantages of doing so (Dunwoody and Ryan 1983; Nelkin 1995). While scientists are wary that communicating to the lay public extends their accountability beyond the scientific community, cooperation among scientists and journalists appears to be growing. This cooperation is occurring in spite of the well-documented differences and problems between the two cultures.

While the previous discussion suggests that scientists, by and large, do understand that they have an obligation to educate the public about science, the panel believes that this attitude needs to become more pervasive. Scientists need to understand that to fulfill this public service obligation, they must interact with the media and other publics external to the peer community. While it is clear that some scientists naturally will be better communicators than others, all scientists have a stake in and obligation to the outcomes of public communication. This obligation may be as minimal as responding to or providing information for a reporter when he or she is contacted, or it may involve more central involvement in an organization's public communication programs.

In particular, the panel finds that scientists need a working knowledge, or "culture appreciation," of the media and how they operate. As Nelkin (1995) suggested, "scientists and journalists must *accept and come to terms with* [emphasis added] an uneasy and often adversarial relationship" (p. 171). Scientists should be taught, through communication training sessions, to recognize that science communication is a field that is backed by rigorous research and strong professional standards. Scientists should also learn that science journalists share common goals of accurate and fair information dissemination.

This public service mind-set needs to be extended to include other efforts. The panel endorses the NSB recommendation in its report on communicating science (NSB 2000a) that scientists and engineers need

> to be more articulate and clear about their work and the good it is doing for society, be more accessible and more accountable, and lead or participate in public information efforts in a wide variety of public forums—from schools to the media. (P. 17)

The panel also echoes the NSB's admonition to scientists and engineers to "communicate the joy and fascination of science as well as its utility" (NSB 1998, 15).

Most academic research and expert advice gathered from the panel's meetings suggest that the active involvement of scientists and engineers at the organizational level also is critical to the success of any science communication endeavor. The panel believes that the most effective science organizations are those that integrate scientists in joint and equal decision making regarding science communication issues, including the content and time frames for release of information. In this scenario, the importance of science communication permeates the entire culture of the organization; organizational leaders place utmost value in this activity.

It must be recognized that organizations for which this cultural shift has been most successful have put institutional reward systems in place. The panel recommends that scientists be rewarded for aiding in the public communication efforts of their organization. These rewards can range from nonmonetary recognition in the form of awards or in-house newsletter articles to more traditional monetary rewards. In practice, it would be wise for organizational leaders to solicit input from scientists about appropriate and meaningful rewards for these activities.

- Finding 5: Science communicators who can foster mutual respect between scientists and external publics are essential to effective public communication of science.

At a recent conference in London, science historian Bruce Lewenstein (2000) of Cornell University traced the origins of communication with the public about science by science institutions back to the genesis of public science museums in the United States at the end of the nineteenth century. These nascent efforts were followed by the rise of scientific societies like the American Medical Association and the American Chemical Society, which began coordinated campaigns to convince the public of the benefits of science as early as 1910 to 1915. With the formation of the National Association of Science Writers in 1934, the communication of science to the public began an evolution from a conscious effort to show the value of science to a more objective, less value-laden reporting of scientific advances that continues to shape American journalistic coverage of science today. By the middle of the twentieth century, noted Lewenstein (2000), public communication about science had emerged as a career in and of itself.

At the same time, though, Lewenstein (2000) pointed out that the nature of science communication activities for the public were determined more by the particular goals and concerns of dedicated individuals—who moved freely among private, commercial, educational, and government positions—than by particular institutions.

Nelkin (1995) noted that despite the growing number of science communicators working for institutions, as recently as twenty-five years ago, institutional science communication was a field many people "fell into" rather than consciously chose as a career. Training was typically on the job, and there were few opportunities for meaningful professional development. In 2000, new entrants to the field of institutional science communication were much more likely to have been trained for the profession by earning a degree or certification from one of several dozen U.S. colleges or universities offering specialty studies in this area (Dunwoody et al. 1998).

Most scientific institutions are decentralized, with a relatively flat organizational structure. Owing to the specialized nature of science, employees of research-performing institutions usually are well educated, and day-to-day decision making occurs at relatively low levels of the organization. In this environment, the science communicator with typically a bachelor's or master's degree in journalism, English, or science communication is often the odd person out. Especially at the senior levels of most scientific organizations, the director of the institution's public affairs or communication office often is one of the few non–Ph.D. trained executives sitting at the table.

To speak with authority under such circumstances, the director of public affairs ideally should report to the head of the agency, department, or museum or to the president of the professional society or university. Short of a direct reporting relationship, the director of public affairs needs unfettered access to the head of the institution on very short notice. Communication decisions typically must be made within very short time frames. Many reporters have daily deadlines, and responses must be developed and communicated quickly. A public affairs director must have easy access—and preferably a direct reporting relationship—to the head of the organization to accomplish timely and informed decision making in responding to media inquiries.

Providing a seat at the table for public affairs also helps ensure that the organization will be better able to consider the public consequences of its actions. Should a minor chemical spill be reported to the surrounding community now or only if a reporter asks about it? Should the organization's Web pages project a united front to Web surfers, or should each of the organization's divisions be free to develop its own format? Should an inquiry from a congressional committee about research facilities be handled by building services experts or by the head of the organization? A forceful public affairs director often will answer such questions differently than will a Ph.D. scientist. Without a seat at the table, the public perspective is often lost, and the organization makes less-informed decisions.

The panel lauds the trend toward professionalization of science communication. It recommends that science communication professionals in research-performing institutions participate meaningfully as part of the organization's senior management. How that relationship is developed and implemented is highly dependent on the nature and structure of the institution, and the panel has reviewed exemplary practices that include direct reports, institutional leadership, dual reporting roles, and the leaders of an institution's research function and its overall leadership.

- Finding 6: The proliferation of new media and the fragmentation of existing media will have profound impacts on how and with whom one communicates about science and technology.

Even given the recent downturn in the fortunes of Internet-based dot-com companies, the trajectory of growth of Internet use in comparison to other mass media is impressive. Stempel, Hargrove, and Bernt (2000) found that subscribing to Internet and online services increased dramatically and listening to radio news and talk shows increased significantly among Americans in national surveys conducted in 1995 and 1999. They found, during the same period, significant declines in watching local and network television news and in reading daily newspapers, grocery store tabloids, and newsmagazines.

In February of 2001, the Pew Internet & American Life Project (Rainie and Packel 2001) estimated that more than 168 million Americans (56 percent) had World Wide Web access from either home or work. On a typical day at the end of 2000, 58 million Americans were logging on—an increase of 9 million from the daily figures just six months previous. The online population is skewed toward the young: fully 75 percent of those between ages eighteen and twenty-nine have Internet access, compared with only 15 percent of those ages sixty-five and older. Moreover, there are significant differences in online access by income, with 82 percent of those living in households with annual incomes of more than $75,000 having access compared with only 38 percent of those in households earning less than $30,000.

The Pew report also noted that the average American user at the end of 2000 spent slightly more than four hours a week online; almost half of their online time was devoted to e-mail, with the remainder pretty much evenly divided between browsing for fun or hobby information and getting news—often health news. This is less than the several hours per day that many adults watch commercial television, but recent Nielsen ratings (data taken from the online Nielsen NetRatings page for the week of 22 July 2001: http://www.nielsen-netratings.com) suggest that Internet use is increasing at the expense of attentiveness to other mass media. The Nielsen data put the estimate of the "current Internet universe" of users at 167 million in July 2001.

Despite the growth and robustness of this medium, the panel does not believe, however, that Internet-based science communication will be the only medium of public communication in the future. Books, magazines, journals, newspapers, and broadcasts continue to be important mechanisms for disseminating scientific information to public audiences, and some of these media—notably broadcast cable—are experiencing rapid growth as well. What the Internet offers is unparalleled opportunity to directly reach audiences of import, especially the science-attentive and science-interested audiences described above. Moreover, the Internet allows direct interaction with scientists and the scientific process in a way difficult to replicate with static media—even though very few communicators take full advantage of this capability.

The panel recommends that scientific organizations manage where practicable a diverse science communication portfolio. Furthermore, each organization should develop Internet-based science communication programs that make full use of the World Wide Web's ability to reach individual users directly, rather than through mass media, and that take maximum advantage of the Web's interactive qualities.

Conclusion

For half a century after World War II, the U.S. scientific enterprise thrived in the context of military preparedness and economic competitiveness with respect to Russian-bloc countries. The end of the Cold War at the conclusion of the past century, however, forced scientists to begin to think more broadly about other societal justifications for research and development and to begin to examine the value of science as a public enterprise. Coupled with stagnant or dwindling fiscal resources since the early 1990s (in constant dollars), this new environment has given an unprecedented prominence to the practice and practitioners of science communication. Unfortunately, other pressures at work in the scientific enterprise—commercialization, economic competition, and dwindling resources—are dictating the nature and scope of science communication in ways that the panel believes may not be fully consistent with better public understanding of science and technology. Rather, many research-performing institutions are adopting marketing, branding, and advertising approaches that may work well in a commercial enterprise but that seldom make an effective substitute for good science communication.

The new century will provide many new opportunities to increase public understanding of science and technology. However, these new opportunities must be based on sound scholarship and evaluation—commodities that the panel finds in very scarce supply among science communication programs in the United States today.

Leaving aside all potential benefits of science communication to increase public advocacy and support for research, the panel believes that better public understanding of science and technology—aided by appropriately designed science communication programs—is a worthy goal in and of itself. The public dialogue that results from effective science communication can be a hallmark of citizen involvement in science for the twenty-first century and the best possible outcome of communication strategies aimed at better public understanding of science, technology, and health.

Notes

1. Panel members included Rick E. Borchelt (chair), U.S. Department of Energy; Debbie Treise (study director), Department of Advertising, University of Florida; Deborah Blum, School of Journalism and Mass Communication, University of Wisconsin–Madison; Lynne Friedmann, Friedmann Communications; Martin Glicksman, Department of Materials Sciences and Engineering, Rensselaer Polytechnic Institute; John M. Horack (ex officio), Space Sciences Laboratory (SSL), George C. Marshall Space Flight Center (MSFC); Robert Logan, School of Journalism, University of Missouri; Paul Lowenberg, Lowenberg Communications; Charles

McGruder III, Department of Physics and Astronomy, Western Kentucky University; Jon D. Miller, Northwestern University Medical School; Gail Porter, National Institute of Standards and Technology; Carol L. Rogers, College of Journalism, University of Maryland; Barbara Valentino, Evolving Communications; Michael Weigold, Department of Advertising, University of Florida; Gregory Wilson (ex officio), SSL, MSFC; and Kris Wilson, Department of Journalism, University of Texas.

2. Meetings were held at The Salk Institute, La Jolla, CA; the Marine Biological Laboratory, Woods Hole, MA; Duke University, Durham, NC; the American Association for the Advancement of Science, Washington, DC; NASA MSFC, Huntsville, AL; Northwestern University Medical School, Chicago; University of California, Santa Cruz; and the University of Florida (meeting held in Jacksonville, FL).

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