This article provides an overview of science communication, which is a vital area of mass communication scholarship. The review is organized around the key players, including news organizations, reporters, science information professionals, scientists, and audiences. Also reviewed is the problem of science communication, which may be partly responsible for widespread science illiteracy. Ways of improving the practice of science communication and an agenda for future research are offered.

Communicating Science

A Review of the Literature

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Media messages about science have long attracted attention from communication scholars (Cronholm and Sandell 1981; Grunig 1979, 1983; Jerome 1986; Lewenstein 1992). Perhaps this is surprising since the attention given science in most news media is small in comparison to that accorded to business, politics, or even sports and entertainment. But, scholars in this area argue that the importance of science news is poorly benchmarked by the attention it receives in most mass media. In an era of unprecedented technological and scientific advances, many of which have the potential to radically change human existence, science news is important.

This article provides a brief overview of science communication scholarship by first attempting to demarcate the subject of science, then presenting the key players (news organizations, journalists, science information professionals, scientists, and audiences) and reviewing research detailing their

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interrelationships. In the final section, I present a subjective agenda for science communication scholarship.

What Is Science?

People use "science" to refer to a broad range of activities. It includes the work of academic scientists seeking knowledge for its own sake (basic science) and the activities of scientists who explore solutions to immediate problems and concerns (applied science). A broad definition of science might include technologists who use fundamental knowledge to develop and design new products, whereas a narrower definition would exclude this group.

Friedman, Dunwoody, and Rogers (1986) proposed a broad definition: " 'science' comprises not only the biological, life, and physical sciences but also the social and behavioral sciences and such applied fields as medicine, environmental sciences, technology, and engineering" (p. xv). They added that " 'science writing' includes coverage of these fields as well as the political, economic, and social aspects of science" (p. xv).

Science writers and journalists confront definitions of science when they decide which activities to monitor and explain. Sharon Begley (cited in Hartz and Chappell 1997) of *Newsweek* suggested that at "*Newsweek*, science is basic research." She continued:

> I cover everything from archeology to genetics, neuroscience, and physics. I do not do medicine, which is defined as anything having to do with sick people. And I don't do technology. I'll do genetics. I'll do neuroscience. But once it gets into somebody sick, I give it to "medicine." (P. 51)

The *New York Times*, in its weekly science sections, also distinguishes "science" from "technology."

Largely unknown is what exactly audiences consider to be science stories. A story on a proposal to build a nuclear power plant may be viewed as a political story, a big-business story, or an economic story as easily as a science story. The importance of science or scientists to many science-related stories may be quite small (Burnham 1987). Recent coverage of lawsuits over breast implants and Gulf War diseases gave relatively little attention to scientific efforts aimed at determining whether victims suffered to a greater extent than might be expected by chance (in both cases, there was considerable evidence that they had not). Science was a part of the stories, but just a small part.

News Organizations and Science

News media have historically accorded science great importance. In the nineteenth century, newspapers reprinted lectures by Thomas Huxley, Louis Agassiz, and Asa Gray, and one issue of the *New York Tribune* published the text of physics lectures by John Tyndall. During the 1920s, press magnate Edwin W. Scripps launched Science Service, a news agency offering the "drama [that] lurks in every test tube." Science coverage may have reached its zenith during the Second World War, when science and technology were seen as integral to victory. The launching of Sputnik led to a reevaluation of science education in the United States and to renewed interest in science generally (Shortland and Gregory 1991).

Modern news organizations are more likely to view science as a niche area; thus, in larger news organizations science may be covered by a beat reporter while in smaller organizations science reporting is more typically handled by a general assignment reporter or by using wire services (Friedman 1986). The medium itself also affects the quality and amount of science news. Most in-depth reporting is done by newsmagazines, followed by large national papers. Wires, small dailies, and broadcast stations are least likely to have the time or money for in-depth science coverage (Ward 1992).

In addition, science news competes with other kinds of news for a relatively small amount of space and time. Friedman (1986) estimates that perhaps 5 percent of a typical newspaper is reserved for news of the day, leading most papers to place heavy emphasis on story brevity and simplicity. Coverage of issues in broadcast reports is even tighter. Because effectively telling science stories often requires considerable background information, science writers face a difficult challenge.

Several researchers have raised the gatekeeping question: how does news about anything, including news about science, pass through the editorial gate to become content? Shoemaker and Reese (1991) suggested all news organizations rely on "craft norms" for generating news. These include prominence/importance (How many lives are affected? Fatalities are "worth" more than property damage. Actions of the powerful are more newsworthy than actions of ordinary people or the poor), human interest (including the activities of people with no direct impact on an audience member's life other than that created by their own fame, i.e., celebrities, gossip, human dramas), conflict/controversy (Conflict is presumed to alert audiences to important issues. It is also believed to be inherently more interesting than harmony), the unusual, timeliness, and proximity (Events that happen nearby are considered more newsworthy). Research has confirmed that these criteria are relevant for a newspaper's decision about science coverage as well (David 1996; Ramsey 1989; Singer, Endreny, and Glassman 1991).

Other constraints that influence news selection include the complexity of deadlines, the unpredictability of occurrences, and the news organization's ability to adapt to physical limits, including limits of time and space (Liebler and Bendix 1997). Reporters rely on routines that provide access to news, such as press conferences, announcements, and scientific meetings. Because of limits of time and resources, reporters often work from "predefined angles" or frames that provide themes around which to build stories (Baker 1986; Shoemaker and Reese 1991).

News organizations also rely heavily on each other for ideas. Gans (1979) argued that editors read elite media such as the *New York Times* and *Washington Post* for story ideas, eliminating the need for an independent judgment of newsworthiness, a function described by media scholars as "inter-media" agenda setting (Breed 1980; Shoemaker and Reese 1991).

Modern coverage of science varies considerably within and across media. Larger newspapers with better educated readers, such as the *New York Times*, "cater to an audience interested in reading about some advances in science or medicine that will be ignored by the editors of the *New York Daily News*" (Burkett 1986, 12). Newspapers that carry regular science sections as compared to those that do not also give greater coverage to science in the news section (Bader 1990), particularly for stories about basic research. Television news, with its small newshole, often squeezes coverage of science to a bare minimum (Altheide 1976).

Competing media may emphasize different aspects of the same story. For example, elite British newspapers emphasize credible sources and science professionals, whereas popular papers focus more on the consumer's perspective (Entwistle and Hancock-Beaulieu 1992). Evans et al. (1990) compared the coverage of science stories between elite and tabloid American newspapers and found that compared to the tabloids, elite media provide more details about findings and methods employed in the research.

News organizations must also make decisions about which science topics to cover (Hilgartner and Bosk 1988). Dennis and McCartney (1979) found that science writers at large newspapers favored stories about medicine, the environment, and technology over stories about the physical and behavioral sciences. And, coverage of scientific ideas is often a function of some newsworthy event rather than the ideas themselves. For example, Caudill (1987, 1989) found that coverage of evolution was less a function of new scientific findings than of anniversaries such as Darwin's death, the centennial of his birth, and the Scopes Monkey Trial. On the other hand, coverage of some issues, such as AIDS, seems less linked to concrete events and other traditional determinants of newsworthiness (Grube and Boehme-Duerr 1988).

Science is also covered in business, trade, or industrial publications that focus on the interests of managers or stockholders in major companies who require more than popularization. For example, while some science writers work as journalists, others work for companies and institutions, "producing reports for a wide range of purposes. There may be press releases promoting a company product, a brochure explaining a process in layman's language, or a magazine for stockholders or employees" (Burkett 1986, 13).

Television creates images of science that in turn have implications for how science is viewed and understood. These images can come from science-related programming, including public television programs such as *NOVA*, commercial programs such as *National Geographic*, and the content of some cable networks, such as the *Discovery Channel* and *Animal Planet*. Such images also can come from programming that is not explicitly concerned with science but in which science plays a dramatic role, such as science fiction programs (Gerbner 1987). Surveying the attitudes and knowledge of consumers of science fiction programming suggests that they constitute another important public of science communication (Banks and Tankel 1990). A number of years ago, fans of the science fiction program *Star Trek* lobbied heavily (and successfully) to have NASA name one of the space shuttles *Enterprise* (see http://www.pao.ksc.nasa.gov/kscpao/shuttle/resources/orbiters/enterprise.html).

Specialty magazines offer some of the richest and most sophisticated coverage of science for general audiences. *Scientific American* employs editors, but it is scientists, not reporters, who write the stories. Less knowledgeable readers who might have difficulty with *Scientific American* can still satisfy their curiosity with "popularized" magazines such as *Discover* and *Popular Science* (Burkett 1986).

Although largely ignored in mass communication scholarship, general audience science books may play an important function in the popularization of science. Such books may represent the public's only sophisticated encounters with physics (Gleick 1987; Hawking 1988), evolution (Wright 1994), language (Pinker 1994), astronomy (Ferris 1997; Sagan 1980), natural history (Gould 1995), geography (National Geographic Society 1976), mathematics (Paulos 1988), or scientists (Boorstin 1983). The popularity and prevalence of excellent books on science topics suggest that there is an audience interested in science issues. Future scholarship is needed to answer some important questions, such as, Who are the readers of these books? What are they learning? What is the quality of science in such books? What are the opinions of readers of science books about science policy? and Are science book readers interested in specialty areas of science or in science generally?

Scholars are also just beginning to explore the impact of the World Wide Web on communicating science. Space does not permit a detailed exploration of this new medium, but it seems clear that it has the potential to dramatically change the relationships of the players in science communication. This is so for at least four important reasons. First, the Web permits scientists and their organizations to communicate directly with audiences. The mediation of news organizations is no longer a necessity. Second, the Web largely eliminates the severe space and time restrictions inherent in ordinary news media. It therefore allows for complex, sophisticated, and interconnected pieces of information. Third, the Web combines the information richness of print with the demonstration power of broadcast in a seamless, accessible, interactive fashion. Finally, the Web is an instantaneous two-way communications medium, allowing one-to-one, one-to-many, many-to-one, and many-to-many interactions. The next decade will doubtless witness a flourish of research papers on the impact of the Web as a communications medium, and much of our current wisdom about communicating science is likely to dramatically change.

Journalists

Weaver and Wilhoit (1996) put the number of U.S. reporters and journalists at about 122,000, but only a small percentage of these reporters have science beats. There are only 600 to 800 individuals who are estimated to work as science and medical reporters (Klaidman 1991) and only about 2,000 individuals who are members of the National Association of Science Writers, which includes print and broadcast journalists, freelance writers, and public information officers (National Association of Science Writers 2001).

Few journalists covering science possess strong science backgrounds (Palen 1994); more commonly, writers learn science on the job (Hartz and Chappell 1997). The vast majority of reporters do have college degrees (84 percent working for newspapers, 95 percent working for newsmagazines), but rarely do they have science degrees. Weaver and Wilhoit (1996) reported that more than 56 percent of journalists with college degrees majored in a communications-related field, while less than 3 percent majored in mathematics, physical science, or biological science. The situation is similar at the editorial level: fewer than one in three editors in a Canadian study had taken a single science course in college (Dubas and Martel 1975).

Encouragingly, specialized science reporters tend to be better educated in science when compared to their general news peers. However, because they lack status in news organizations, it is likely to be a general reporter, not the science writer, who is given the assignment when a fast-breaking news story deals with science. Science reporters hold somewhat different news values than regular reporters, favoring alternatives to hard news because such alternative formats allow more effective communication about science issues (Friedman 1986; Glynn 1988).

Science writers approach their task differently depending on organizational constraints. Dunwoody (1979) found that reporters covering the annual meeting of the American Association for the Advancement of Science (AAAS) who were working under strict deadlines were more dependent on press conferences and therefore on the sponsoring organization than were reporters with fewer time constraints. In addition, the more stories a reporter was expected to write, the greater was the reporter's reliance on press conferences. The majority of stories produced by reporters with daily deadlines were single-source stories, while the majority of stories written by reporters with fewer constraints involved two or more sources. Since good reporting requires input from several sources (Rubin and Hendy 1977), why do many reporters rely on one or two? It may be because they often do not know where to find sources for science-related issues (Friedman 1986).

Groups of prominent writers at science conferences may form an "inner club," with those writing for elite papers at the top (Dunwoody 1980). These writers pool resources in deciding what to cover and how such coverage is to be formulated. Altimore (1982) echoed this theme when he wrote that science reporting "is characterized by an inordinate degree of collaboration and communication among reporters, and science journalism is quite homogeneous in its view of what qualifies as science news" (p. 25).

Science writers and their editors do not always agree on the types of science stories readers will find interesting (Dunwoody 1986b). And editors, as compared to science writers, scientists, and lay persons, are more likely to favor sensationalism and less likely to favor accuracy in judging newsworthiness (Johnson 1963). Dubas and Martel (1975) found that city editors tend not to be very discriminating in selecting science stories, preferring stories with a sensational angle or an element of conflict, or in some cases dismissing the relevance of science stories altogether. Not surprisingly then, many science writers are unhappy with the priorities of their editors (Dennis and McCartney 1979), believing they like to scare readers, ignore continuing stories, and waste space and air time on junk. At the same time, since editors often write story headlines and control story revisions, science reporters sometimes write for editors rather than the public (Friedman 1986).

Science Information Professionals

Many times, the communications link from scientist to reporter will travel through a science information professional, or public relations person (also known as public information, public relations, communications, public affairs, news service, and media relations). Science information professionals are common in most large scientific societies, universities, major research laboratories, and industrial organizations (Rogers 1986).

Science information professionals often have trained as reporters, meaning they likely have little or no formal education in science. Increasingly, young persons trained in science journalism end up working as science information professionals instead of as journalists, perhaps reflecting job market realities (Rogers 1986). Science information professionals serve as spokespeople for their organizations, frequently appearing before community groups and media. They may also run speakers' bureaus and coordinate special events; produce brochures, booklets, or reports; act as advisers to top officials within organizations; and help individual scientists work more effectively with media.

The professional may be asked to help interpret implications of new developments, suggest ways of dealing with media, and suggest the kinds of information that should be released to a public. He or she may be asked to produce how-to books for scientists dealing with media. Often, the science information professional is a liaison between scientists and reporters. The role of boundary spanner is difficult because of the conflicting roles of scientists and journalists, yet it can be an effective one. For example, more than half of the scientists in one study reported that mediation occurred in their interactions with reporters and that it resulted in more accurate stories (Dunwoody and Ryan 1983). In addition, the science information professional orients reporters to ongoing research activities within the organization. Research suggests that most reporters covering the AAAS meeting use news conferences to help determine what is important, and content analyses of print and other media show that science information professionals are the major sources of information from the meetings.

Unfortunately, these individuals are often low in the hierarchy of their own institutions. Their efforts are supported with small budgets and few resources. They typically receive no credit for the stories about science that appear in the news. In the worst cases, the professional's news release may be carried verbatim but with a reporter's byline. Scientists see the professionals as too close to the media, journalists see them as "flacks" for scientific organizations, and both view them as representatives of organizational administration (Rogers 1986).

Scientists

Burkett (1986) estimated that 3 million persons were employed in the United States as scientists in the early 1980s, and more recent estimates suggest that number has held relatively constant (Commission on Professionals in Science and Technology 2001). The number of individuals with at least a bachelor's degree in science or technology who are employed is closer to 10 million (National Science Board 2000). The science workforce is supported by a large amount of public and private spending: U.S. research and development expenditures are estimated to be $227 billion as of 1998, although research and development spending as a percentage of gross domestic product has declined since the early 1990s (National Science Board 2000).

With some exceptions, most working scientists have little responsibility for dealing directly with the public. An elite group of scientists, however, especially those who publish in journals monitored by the press, are often sought for interviews by media reporters. Among the journals regularly scanned by science journalists are *Science* (the weekly journal of the AAAS), *Nature*, the *New England Journal of Medicine*, and the *Journal of the American Medical Association*. These journals frequently "speak not only of the technical matters of science but also of policy, politics, and conscience" (Burkett 1986, 8). Some famous scientists also are given relatively direct access to the public by news organizations. These "visible scientists" include Nobel Prize winners, heads of prestigious institutions, and administrators of science-oriented agencies and labs (Goodell 1977).

There is a widespread perception that scientists are not effective communicators, at least when the audience is the general public. Dr. Neal Lane (cited in Hartz and Chappell 1997), former head of the National Science Foundation, claimed:

> With the exception of a few people . . . we don't know how to communicate with the public. We don't understand our audience well enough—we have not taken the time to put ourselves in the shoes of a neighbor, the brother-in-law, the person who handles our investments—to understand why it's difficult for them to hear us speak. We don't know the language and we haven't practiced it enough. (P. 38)

Most scientists appear ready to improve their skills, since more than 80 percent of scientists in a recent survey said they were willing to take a course to help them learn to communicate better with journalists. Roughly the same amount, 81 percent, are at least somewhat willing to make the effort to communicate with the public (Hartz and Chappell 1997).

The scientist who wants to communicate directly with a public about issues of science faces several important hurdles. Perhaps the most basic of these is language. As recently as 1920, the language used in a journal such as *Nature* would be comprehensible to literate audiences and would not sound dramatically different from other forms of literature. But now, scientific language has “diverged from the mainstream of literary language and divided into a large number of small, winding tributaries” (Shortland and Gregory 1991, 12). Hence, the scientist must be skilled at translating ideas from the technical language of his or her discipline into a currency accessible to lay audiences.

Some people, including a number of scientists (Eron 1986), argue that scientists have a basic responsibility to interact with the public. Yet, scientists are often reluctant to engage in public dialogue. Fellow scientists may look down on colleagues who go public, believing that science is best shared through peer-reviewed publications. Scientists may also believe that broadcast media are trivial, that scientists should be humble and dedicated to their work, that scientists should have neither the time nor the inclination to blow their own trumpets, that the rewards of a media career can compromise a scientist’s integrity, that the public may commandeer a story and distort it, and finally that the public may get excited about the wrong side of the story (Shortland and Gregory 1991).

Audiences

Large numbers of American adults appear to be scientifically “illiterate” (Maienschein and students 1999), leaving many to conclude there is a “problem” in science communication (Dornan 1988, 1990; Durant and Evans 1989; Durant, Evans, and Thomas 1992; Hartz and Chappell 1997; Trachtman 1981). Ziman (1992) proposed three ways to view the problem: the deficiency model, the rational choice model, and the context model. The deficiency model suggests that widespread ignorance about science is a problem because scientists in democratic societies depend on public goodwill for funding and support. If ignorance of science can be reduced, the public’s attitude toward science will be positive, resulting in ever-increasing levels of economic support. Ignorant publics are vulnerable to the antiscience messages of those who would cut science funding. Since most adults encounter science information only from media coverage, ignorance is best reduced via effective communication about science. Effective communication would help adult nonscientists to become more literate about what scientists know. The model’s appeal is enhanced by findings that show widespread scientific illiteracy in major democracies (Hartz and Chappell 1997) and by evidence that attitudes toward science may be growing more negative (Yankelovich 1982).

But, the deficiency model has important problems, including what some (Gregory and Miller 1998; Trench 1998) claim is its top-down, science-centered approach. And, there may be logical problems with asserting that a body of knowledge exists ready to be communicated to the uninformed since science is not "a well-bounded, coherent entity, capable of being more or less 'understood' " (Ziman 1992, 15). Scientists themselves have no clear and consistent notion of what science covers and often disagree about what it tells us about the world.

A second perspective is the rational choice model. It asks, "What do people *need* to know in order to be good citizens—even to survive—in a culture largely shaped by science?" (Ziman 1992, 16). Without sufficient knowledge, people might not live their lives optimally, or they might even turn against science. But, dilemmas plague this approach too. For example, given conflicts among scientists over findings and theory, whose advice should be followed? What advice is necessary? Where should such advice be located?

Finally, the context model asks, "What do people want to know in their particular circumstances?" (Ziman 1992, 17-18). This model requires understanding of the context of scientific knowledge and how different people put it to use. Lewenstein (1992), Logan (1999), and Ziman (1992) have argued that science communication scholarship could benefit from adopting this third perspective.

National Science Foundation surveys report that almost 90 percent of U.S. adults claim to be interested in news about science and technology. Below the surface though, evidence suggests that the public can be divided into at least three segments according to level of interest in science (Miller 1986; Prewitt 1982). Miller (1986) originally estimated that about 20 percent of American adults are attentive to science policy. This group tends to be younger, male, better educated, and more likely to have taken a college-level science course when compared to the broader population. There is also evidence that this group is shrinking, as recent surveys now suggest attentives number between 10 and 14 percent of the population (National Science Board 2000).

Another 44 percent of the public can be characterized as "science-interested" (National Science Board 2000). These individuals have a relatively high interest in science and technology but lack functional understanding of the process or terminology of science. Compared to the science-attentive public, science interesteds are slightly older, somewhat less educated, and less likely to have had a college-level science course (Miller 1986). In line with Miller's (1986) findings, Palen (1994) reported that 56 percent of

Americans are regular viewers of television programs on science, technology, or nature, and 38 percent read science news in a newspaper weekly.

While many people profess interest in science, the unfortunate reality is that two-thirds of even the attentive public cannot pass a "relatively minimal test of scientific literacy" (Miller 1983, cited in Miller 1986, 66). Among the public as a whole, knowledge levels are even lower: fewer than half of the respondents to a recent national survey could correctly answer whether humans lived at the same time as dinosaurs, electrons are smaller than atoms, antibiotics kill viruses, lasers work by focusing sound waves, or it takes the earth one year to travel around the sun (National Science Board 2000). But, science knowledge is not unique in this regard; Americans appear pretty ignorant in other areas too. Popular books assure us that Americans do not know much about history (Davis 1999b), geography (Davis 1999a), computers (Gookin 1999), mathematics (Paulos 1988, 1995), or almost any specialty area.

Such findings raise questions about the content of public understanding of science, leading some to question, What should the public understand? Should the public know about recent developments in science? Should it exhibit science literacy (i.e., basic understanding of accepted scientific facts and theories)? Should the public understand the methods of science? Should it possess insight into the implications of scientific findings? Is it important that the public understand all of these things or some combination of them?

The traditional view holds that all citizens ought to be scientifically literate, as a means of ensuring their full participation in science policy formulation. Yankelovich (1982), a proponent of this view, argues that the general public must be a target of science communication. But others, including Prewitt (1982) and Miller (1986), believe that science messages are often wasted when disseminated to the general public. They suggest segmenting the public according to where individuals exist in a science hierarchy. At the top are decisionmakers in government and policy with specialized science information needs. These decisionmakers increasingly have to make comparative judgments about science and technology matters, which require a high degree of scientific literacy to ensure that wise science policies are developed and implemented. The attentive public also requires an understanding of the process of scientific study and a "functional understanding of the major constructs used in scientific discourse [for example, molecule, gene, cell]" (Miller 1986, 61). The information needs of the interested public are more difficult to address. Miller (1986) speculated that any approach to communicating with this group should be nontechnical, simple, and pictorial. Finally, there is little consensus about the information needs or wants of the nonattentive public.

Almost 80 percent of the attentive public watch news shows regularly, and roughly the same proportion of the interested public watch the news. About 75 percent of attentives regularly read the paper, but they are dissatisfied with the science coverage they find there, and just 9 percent rate the paper as a good source of science news. About half of the attentive public are regular readers of one or more science magazines, including *National Geographic* and *Psychology Today*. But, fewer than 10 percent are readers of general science magazines such as *Science*, *Discover*, or *Scientific American* (Miller 1986).

Beyond basic scientific facts, it is interesting to consider what people understand about the work of science and about the lives of scientists. Science is not a visible occupation, and people rarely observe scientists at work. LaFollette (1990) analyzed how popular magazines appearing between 1910 and 1950 presented images of science. She found that the valence of images of science and scientists have waxed and waned through the years. Magazines generally linked science to national progress and economic health, and the general trend over fifty years is an increase in articles about science.

The attitudes people hold toward science appear to be complex as well. Angell (1996) argued that the United States is in the midst of a groundswell of antiscience feeling, pointing to renewed opposition to the teaching of evolution in public schools as an example. Ironically, and perhaps not coincidentally, such sentiments come at a time when people are more dependent on science than ever. Yankelovich (1982) reported that the present image of science is somewhat less positive than it was earlier in the century. A bare majority now agrees that "technology will find a way to solve the problems of society," and fewer people agree that "everything has a scientific explanation." More recent surveys show conflicting public attitudes: two-thirds of respondents agree that "science is the best source of reliable knowledge about the world," but almost 40 percent of the public agree that "technology has become dangerous and unmanageable" (National Science Board 2000).

Audience attitudes may be influenced by the tone of coverage as well. An analysis of biotechnology accounts from 1970 through 1996 (Lewenstein, Allaman, and Parthasarathy 1998) found that coverage has, over time, been consistent and emphasized positive outcomes. Findings from several studies suggest that no single generalization about tone may be appropriate for all media at all times. The tone of elite media coverage of the theory of evolution changed from doubting to supportive during the early part of the twentieth century (Caudill 1987). Bowes and Stamm (1972) found that the tone of media coverage of a flood control project became more positive following the growth of public opposition to the project.

Whether reporting acknowledges or fails to present controversy in science is related to the tone of news accounts, since controversy can signal a negative tone. Cole's (1975) content analysis of newspapers during the 1950s, 1960s, and 1970s found controversy more likely in articles from the 1970s than from the earlier times. Collins (1987) suggested that television typically ignores science controversy unless a story relates to another current issue. In Canadian papers, meanwhile, the overall tone of science articles is positive, according to one content analysis (Einsiedel 1992).

Agenda-setting research posits that the prominence of issues in news media can affect the salience given to the issue among audiences (McCombs and Shaw 1972, 1993). Pilisuk and Acredolo (1988) surveyed three communities, concluding that regular use of broadcast media is unrelated to concern about technological risk. Conversely, Albert (1986) suggested that magazine coverage of AIDS in the early 1980s contributed to a climate of blame for those who have the disease. At the same time, Baker (1986) contended early news coverage of AIDS at an elite newspaper influenced perceptions of the disease as a legitimate social issue.

Mazur and Conant (1978) found that people who have heard about a proposed nuclear waste site are more opposed to it than are people who have not heard about it. Mazur (1981a, 1981b) concluded that media coverage of a scientific controversy increases public opposition to the technology, even when such coverage is not negative. McLeod, Glynn, and Griffin (1987) found that greater media use is associated with higher ratings of the importance of energy. Placing an issue high on a public's issue agenda can carry benefits. For example, one study found that there was an increase in the early detection of colon cancer following the extensive media coverage of then President Reagan's colon cancer surgery (Brown and Potosky 1990). And, events such as Earth Day can spur coverage of environmental issues, even as the coverage emphasizes some environmental problems at the expense of others (Bowman and Hanaford 1977).

There is a great deal of science reporting about risk, and this is one area in which public interest seems high. The reasons for this are obvious. Scientific discoveries can help people to avoid health threats (encouraging people to eat better and exercise more), detect threats (new technologies can help with early diagnosis of disease or illness), or identify threats (link radon to soil or link cell phones and smoking to cancer). There seems to be broad agreement that a distinction can be made between the "objective reality" of risks, as evidenced by statistical estimates from experts, and social perceptions of risk (Bradbury 1989; Golding 1992; Renn 1992). The divergence of the two may be, in part, an issue of the extent and the way in which risk is covered by the press (Burnham 1987; Viscusi 1992).

Papers dealing with risk issues cover a diverse set of phenomena. Prominent are coverage of the Chernobyl incident and other nuclear issues (Burkett 1986; Nimmo and Combs 1985; Norstedt 1991; Peters 1992; Peters et al. 1990; Rossow and Dunwoody 1991; Rothman and Lichter 1987; Stephens and Edison 1982), AIDS and HIV precautions (Dunwoody and Neuwirth 1991; Singer, Rogers, and Glassman 1991; Stroman and Seltzer 1989; Witte 1995), asbestos (Freimuth and Van Nevel 1981), earthquakes (Atwood 1998) and other natural disasters such as Mount St. Helens (Burkett 1986), the environment (Schoenfeld 1979), technology generally (Pilisuk and Acredolo 1988), water safety (Griffin, Neuwirth, and Dunwoody 1995; Kahlor, Dunwoody, and Griffin 1998), and food safety (Juanillo and Scherer 1995), including pesticides, color additives, dioxin leaching into milk from containers, and growth hormones in animals (Juanillo and Scherer 1995).

Whereas the literature on science communication often portrays the reader as relatively passive and uninvolved, audiences for information about risk are often portrayed as active (Grunig 1974). For example, in 1989, there were 250 organized boycotts of food products, up from 100 to 150 in a typical year (Juanillo and Scherer 1995). Consumer confidence about the safety of food dropped from 81 percent to 65 percent between January and June of 1989 (Mueller 1990). Policies about nuclear energy, food irradiation, tobacco legislation, waste disposal, needle exchanges, disease prevention, and many other concerns are often more affected by the perception of risk than by the quantified predictions of experts. Among other things, perceptions of risk are affected not only by statistical probabilities but also by feelings of dread and by the extent to which the threat is either well understood or unknown (Slovic 1992).

Since society must tolerate a degree of risk, "classical risk communication essentially translates as advocacy for determining which risks are acceptable" (Juanillo and Scherer 1995, 278). When risks are identified or labeled as concerns, stakeholders, including "experts, policy makers, interest groups, and the general public" (Juanillo and Scherer 1995, 279), become involved in debates about policies that are designed to increase safety. Media, although not explicitly mentioned in the list, deserve a place as well because information from media influences many risk perceptions (Slovic 1992; Viscusi 1992).

Conflicts among the Players

The science communication literature offers many perspectives on ways in which the interests, goals, values, and routines of scientists and science journalists clash. These differing values may, in part, be responsible for misunderstandings and disagreements that can hinder relationships between journalists and scientists.

Journalists' norms appear frequently to contradict those of scientists. Journalists are attracted to stories that feature controversy and to new, even tentative, results that carry exciting potential. Norms of fairness lead journalists to balance views of a topic rather than appeal to a single authority, even if a disparity exists in the qualifications of the sources. Reporters face strict, inflexible deadlines. No matter how technical or abstract the issue, a journalist must write in prose that appeals to the broadest possible audience. In addition, journalists write knowing that their copy will be judged, edited, and screened by an editor, who may not be interested in science (Shortland and Gregory 1991).

Journalists may view scientists as narrowly focused, obscure, and self-absorbed. Scientists are specialists, involved in the minutia of a specific problem that may represent a small piece of a much larger puzzle. This can make it difficult for them to state why their most recent discovery is a newsworthy event or even a significant development. Scientists offer predictions that are tentative and qualified, which may seem incompatible with fostering excitement in a story. But, bringing scientific and reporting values into line is not simply an issue of making scientists less humble in their writing. In many cases, the importance of scientific work is not immediately obvious. In almost all cases, new discoveries are only an incremental part of a larger undertaking (Valenti 1999).

An important value of science is objectivity, not so much in the choice of questions or theories, but in requiring tests that permit theoretically incompatible outcomes. For scientists, hypotheses must be falsifiable, and tests of the hypotheses must be replicable, so that others working in the discipline, including those with contrary theoretical views, may subject theories to rigorous scrutiny. Conversely, journalism is a subjective enterprise. Indeed, some news organizations, such as the *Washington Post*, have abandoned the idea of objectivity for the somewhat different concept of "fairness" (see http://www.presswise.org.uk/Objectivity.htm). Long-term enterprise stories (health, government performance, and quality of life) are those that lead to Pulitzer Prizes, yet these typically adopt a value-laden point of view.

Journalists have a great deal of confidence in scientists, more than they do in their own profession or in other major institutions. Journalists disagree (80 percent) that scientists who give interviews are publicity seekers and agree (80 percent) that scientists are at least somewhat accessible. Looking in the mirror, few journalists agree that a professional code for journalists ensures high standards. A substantial majority agree that the "biggest problem with science reporting is that it only tells a small part of the whole story" (Hartz and Chappell 1997).

Reporters do offer some specific criticisms of scientists. Some feel that scientists lack incentives to talk to small newspapers and that scientists and industry researchers have vested interests (Crisp 1986; Kiernan 1998). Russell (1986) argued that "for scientists, science communication with a lay audience is almost always a secondary issue. Of first importance, from a professional standpoint, is the business of science itself" (p. 83). She charged that scientists can be difficult to track down and reluctant to return calls. If reached, scientists "talk in the most technical language possible and are fearful of being misquoted" (p. 84). Not escaping criticism are scientists who do cooperate with reporters but

> who might be considered a bit too helpful in their efforts to utilize the press. Some researchers are interested in popularizing not only science but also their own reputations. They even seek out writers with the help of their own public relations agents. (p. 85)

Explaining why some scientists may make themselves available, Russell believes that "the overly cooperative category also includes scientists with a cause to push or a political point of view to promote" (p. 85).

Conflict sometimes emerges between scientists and journalists over ownership of information about science. Breaking news about science is often introduced at controlled events, such as scientific meetings or press conferences, or in journals. But, reporters may also find out about important stories via leaks from politicians, the actions or suspicious activities of key players, and articles in small trade publications. Conflict between scientists and reporters can emerge when scientists or journal editors attempt to control the information, for example, through the use of news embargoes (Kiernan 1998).

In addition, scientists may hold that the emphasis on newsworthiness can create distortions in the reporting of scientific findings, characterized by the charge of "sensationalistic" coverage (Gorney 1992). Scientists claim that media coverage should educate and provide complete, nuanced descriptions of scientific findings (Friedman, Dunwoody, and Rogers 1986). But, the scientist may find that:

> the media have other agendas, and public education per se is not necessarily primary among them. Thus, efforts to inform the public about research in advance are unlikely to succeed, because in the absence of controversy, scandal, or—yes—violence, it isn't considered news. (West 1986, 40)

Scientists may also perceive that journalists ignore the balance of scientific evidence, giving equal weight to those presenting a broad scientific consensus with “maverick” scientists (Crisp 1986; Dearing 1995; Nelkin 1995).

An analysis of the poor quality of press coverage of scientific findings concerning violence and mass media concluded that researchers and reporters have different responsibilities to different audiences, peers, and employers (Eron 1986). The scientist’s primary responsibilities are to disseminate information, educate the public, be scientifically accurate, not lose face before colleagues, get some public credit for years of research, repay the taxpayers who supported the research, and break out of the ivory tower for the sheer fun of it. The journalist’s goals are to get the news, inform, entertain, not lose face before his or her colleagues, fill space or time, and not be repetitive. Sometimes these divergent agendas work to mutual benefit, but at other times they lead to conflict (Tavris 1986).

A recent survey of scientists and journalists confirmed that scientists hold negative views of reporters (Hartz and Chappell 1997). For example, only 11 percent of scientists have a great deal of confidence in the press, while 22 percent have hardly any confidence. More than nine out of ten scientists agree that few reporters understand the nature of science and technology, especially the “tentativeness of most scientific discovery and the complexities of the results” (p. 29).

Scientists view themselves in a far more positive light. Almost 77 percent have a great deal of confidence in themselves and their colleagues, while 80 percent disagree that they waste the taxpayers’ money. Most (72 percent) want the public to know about their work, but a significant minority (40 percent) is afraid of being embarrassed before their peers by news stories about their work. Most are willing to talk with reporters, but hardly any actually do so on a regular basis (only 4 percent as often as once a month). More than a quarter of the scientists from the sample have never appeared in the popular press.

Differences in defining the boundaries of legitimate science also can cause conflict. Griffin and Dunwoody (1995) examined how advocacy groups provide information subsidies to news organizations in an effort to get coverage of an issue the group believes important. Their work raises a more general issue frequently ignored in the science communication literature, namely the influence of nonscientists on ways that publics encounter science news. In fact, journalists frequently adopt (in the scientists’ view) an overly broad definition of who is qualified to comment on scientific issues. Thus, political activists for issues such as animal rights, nuclear power, the environment, the educational system, disease-afflicted groups, and so on may be presented to the public as qualified experts on issues of science. This raises a problem of evidence versus assertions. Reporters rarely ask how sources know what they know, or what evidence the knowledge is based on, or why it differs from conventional wisdom (Tavris 1986):

> Knowing little about methods and the differences among psychological disciplines . . . many media people have never learned to be critical, what questions to ask. Moreover, it is the nature of the social science to produce many contradictory, conflicting studies. To journalists, however, it often seems as though if they don't like what one report says, another study will confirm their prejudices and appear in 20 minutes. (Tavris 1986, 24-25)

Dunwoody (1986a) explored the issue of the costs and benefits for a scientist wishing to use the mass media to communicate science. There is great risk for scientists because while they will find few tangible rewards for informing the public, there are many concrete costs. Within the scientific community, public communication activities are seen as distracting from efforts to do research or even as grandstanding. In addition, public understanding of science carries little currency among scientists.

Relatively few empirical studies have examined direct contact of media and scientific organizations. In one, DiBella, Ferri, and Padderud (1991) suggested the primary motive of scientists for giving media interviews is to help educate the public about science. In another, Dunwoody and Ryan (1987) found that while scientists are generally asked by the press to comment on topics related to their research expertise, about one-third of science-reporter interactions deal with issues having little or no relationship to the scientist's research.

Scientists fear that their own culture does not value direct contact with the public via general news media (Dunwoody and Ryan 1985). Although this might suggest an important role for intermediaries such as public information professionals, Dunwoody and Ryan (1985) found that scientists, while expressing a positive attitude toward public information professionals, consider them to be of only modest importance in disseminating information about science.

How Can Science Reporting Be Improved?

Improving science communication may involve changes in the way that science journalism is practiced. Indeed, the very label "science journalism" obscures the diverse activities ranging from coverage of basic science in specialty magazines to reports on important science stories at elite papers and local news accounts of emerging local issues with a technological angle.

Journalist Training

Journalists almost always lack science training. One study suggests that "journalists tend not to have even a liberal-arts background in the sciences. Few understand the scientific method, the dictates of peer review, the reasons for the caveats and linguistic precision scientists employ when speaking of their work" (Hartz and Chappell 1997, 22). When a journalist lacks the background to evaluate or understand complicated scientific issues, he or she is forced to deal with the subset of available scientists who are skillful at translating complicated issues into simple prose. But, such sources may be quite rare. An alternative is for news organizations to invest in or at least to expect better training in science and technology from their reporters. It is common, for example, for university journalism programs to require that students develop a basic familiarity with the workings of government, with communication law and policy, and with history. Far less common is a requirement for basic scientific or mathematical literacy.

Although it may seem obvious that improving the science training of reporters will enhance the quality of science journalism, this proposal is controversial (Hartz and Chappell 1997). Those who resist the idea offer the following rationales: (1) some outstanding science reporting is done by individuals with little formal training in science, (2) reporters with excellent reporting skills can get scientific sources to explain research in simple and accessible terms, and (3) it is impractical for most people to receive enough training to serve as an expert across multiple disciplines of science, such as chemistry, biology, medicine, psychology, engineering, and physics. One can accept the first two points and still believe that science reporting is improved when journalists receive training in a scientific discipline. The final point introduces a more difficult issue, and the task of covering all of science may be too broad for one person. Rather, such coverage may require specialization, the same way reporters may specialize in covering the White House, Capitol Hill, and the Supreme Court.

Finally, recent work (Trumbo, Dunwoody, and Griffin 1998) has approached the issue of inaccurate science reporting from a different perspective. This perspective locates accuracy problems as originating with fairly well-understood cognitive limitations on the part of reporters. This line of research may be important in shifting the debate away from norm differences (which are unlikely to change) and toward better reporter training as a way of improving science coverage. Specifically, reporters could be trained to identify and overcome the cognitive shortcuts they use that lead to inaccurate news accounts.

Focus on Audience Needs

Crane (1992) advocated that reporters take advantage of preexisting interests of audiences. She suggested that reporters routinely specify for the audience, "Why is it important for me to know about this story?" (p. 29). Science journalism should also characteristically provide more background information and provide perspectives on what a story implies for the broader society. Effective science journalism should provide new information and connect science to everyday life (Bostian 1983; Bostian and Byrne 1984; Hunsaker 1979).

Another way to improve communication is to focus on style. Conventions of journalistic style date to formulas generated in the 1930s: simple words, short sentences, and an inverted pyramid for organizing information. Yet, according to Dunwoody (1992), "to this day in the world of journalism, there is very little attention paid to what people actually get out of the stuff that they read. There are still a lot of assumptions being made" (p. 102). Rowan (1989, 1991a, 1991b, 1992) presented a number of recommendations for improving science writing. She began by asking the journalist to focus on explanation, which she defined as "anticipating and overcoming likely confusions" (Rowan 1992, 131). Those who effectively explain possess a conviction in the value of good explanation, large and easily accessed collections of explanations and conceptual frameworks for determining why ideas are likely to be difficult for audiences, and strategies that best overcome these obstacles.

Interestingly, although accuracy in science reporting is an enduring concern (Ryan 1979; Ryan and Owen 1977; Singer 1990; Tankard and Ryan 1974), the studies that have examined the issue often have found general satisfaction among scientists with news story accuracy. For example, newspaper coverage of research appearing in the *New England Journal of Medicine* was generally accurate in distinguishing facts from opinion (Caudill and Ashtown 1989). And, scientists asked to comment on science content in magazines (Borman 1978) and on television (Moore and Singletary 1985) reported accuracy was, on balance, good (Pulford 1976).

Work More Closely with Sources

Broberg (1973) examined the changes that scientists would make to stories about their research and found that additions are the most common correction. This is consistent with other research suggesting scientists' major contention with press coverage concerns omissions rather than misstatements (Borman 1978; Dunwoody 1982). Greenberg and Wartenberg (1990) analyzed network news coverage of disease and teen suicide to determine whether such coverage provided an accurate portrayal of the geography of the diseases and concluded the coverage was accurate (see also Greenberg et al. 1989).

The task for journalists is daunting, however. Siegfried (1992) summed up the constraints on newspaper coverage by writing, “The truth is that in daily newspaper journalism there is very little room or place for any real explanation. Cancer is cured, fewer people will die—that’s the end of the story in the daily newspaper” (p. 113). Ward (1992) argued the situation is even worse when considering how science is covered on television news shows. The length of the average sound bite on television is six seconds. The importance of compelling visuals leads producers to require personalization (show me someone who has got the disease) and a news peg.

Future Directions in Science Communication

Science communicators have mapped out an ambitious agenda. Science communication research has long been concerned with what people do with the knowledge they gain from media. This strong record of achievement is most clear in the area of risk communication, where investigators try to discover how people react to information about technological threats. More research might be devoted to how people use other kinds of science knowledge. For example, how do people use information about astronomy, earth science, physics, chemistry, and other topics that do not necessarily or directly involve risk? And, how should science activities with no immediate payoff be framed and covered?

Even learning, as defined above, is too restrictive for representing science communication scholarship. A broad set of attitudinal questions is also present in the literature. These questions concern how people form attitudes toward science, scientists, technology and specific technologies, funding of science, science education, and science policy. Attitudinal and opinion issues such as these find their intellectual roots in persuasion theory, in theories of public opinion, and in political science. Especially important and useful would be efforts to link specific science and technology attitudes to the types of knowledge that people have about science.

A prevalent assumption in the literature is that high levels of knowledge correspond to favorable attitudes toward science (Schibeci 1990). But, there are few data on this critical issue (Althoff, Grieg, and Stuckey 1973). It may be just as logical to assume that moderately high levels of knowledge are associated with antiscience attitudes. It does not seem unreasonable to hypothesize that radical environmentalists, antinuclear activists, opponents of cloning and genetic research, animal rights protesters, and others who express narrow or broad opposition to scientific research efforts might actually possess greater levels of understanding of science and the scientific method than do members of the nonattentive public. This is not to say that these groups possess high levels of understanding, merely that they have at least some understanding, if for no other reason than because they are frequently forced to defend their beliefs. This prediction suggests there may be a curvilinear (U-shaped) relation between science knowledge and science attitudes. If science communication is concerned with the kinds of knowledge that foster greater appreciation of science, it also must be concerned with the kinds of knowledge that foster antiscience sentiments.

Attitudinally related questions should also be more specifically framed. One's general attitude toward science (i.e., science is good) may be very different from attitudes toward specific issues (cloning, space exploration), scientists (odd characters, role models), general science support (we are spending enough on science now), and specific support (we need to spend less on AIDS research and more on cancer, or we should fund a greater number of modest physics experiments and fewer big experiments, or too much money is spent on medical research and not enough on chemical research). Understanding people's beliefs and attitudes about science would give us a much better understanding of science publics. Attention should be given to the implicit notion described by Ziman's (1992) deficiency model, namely that knowledge → attitude → funding. A failure to find such predicted links would confirm that issues of science literacy and support are quite different and should be treated as distinct problems.

Science communication research has examined many sociological and public-policy questions. These include the sociology of news and factors affecting the behavior of reporters, sources, news organizations, scientists, and news publics. Increasingly, scholarship in this area is examining the impact that nonscientists have on science-related questions. This is an extremely important area of research because it is centrally related to science policy. What role do activists play in science communication? How do decisionmakers obtain their science news? How is science policy made? When does the public play a role in science policy? What issues do policymakers contend with in decisions to support science and specific research activities? How do journalists balance their needs for close working relationships with scientists with their needs for autonomy? Do journalistic norms for the coverage of government and policymakers hinder or enhance the quality of coverage of scientists? What is the effect of a reporter's own science literacy on his or her coverage of science, selection of stories, choice of sources, and quality of reporting?

Science communication has immeasurably enhanced our knowledge not only about how science information is communicated but also about mass communication processes more generally. This healthy and vibrant area of scholarship is likely to become even more central to the discipline of mass communication. The special challenges presented by communicating the complex and important issues of science will only grow in importance in this new century.

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