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THE DYNAMICS OF SCIENTIFIC CONTROVERSIES

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Science controversies can be distinguished from one another on whether the issue of controversy is a matter of ethics, a matter needing further scientific research, or a need to make public policy decisions on the basis of incomplete information. Effective communication about the relevant issues underlying any science controversy can be improved with education about both the facts and the process of empirical science. Improved communication strategies may support the public interest in science, more effectively incorporate the public voice into policy outcomes, and improve the level of trust between the public and the research scientists.

Key words: genetically modified foods; controversy; education; science communications.

The public wants to know the truth with respect to scientific issues. And scientists want to tell the public the truth about the issues that concern them. Unfortunately, trying to distill the messy realities of scientific research into immutable bullet points (which generally seems to be what the public wants) often undermines the whole notion of understanding. With respect to the important questions on today's frontier of science, "truth" is frequently an amalgam of our best (and imperfect) understanding of an issue and the assumptions that we believe at the time to be valid. That is to say, our knowledge is mutable: As science progresses, what we understand or assume today may well be superseded by what we understand and assume in the future. However, it is the very process by which science naturally progresses that can damage the trust that exists between the scientist and the non-scientist.

Science As A Process

Basic research entails the investigation of a huge variety of ideas, but only a handful of these ideas will lead to an exciting new discovery or to some technology that becomes widely used. In fact, the search for new knowledge often leads to dead ends or discoveries which are, at best, of minor importance and which, when taken out of the context of how scientific research is done, can engender misunderstanding and sometimes become the objects of ridicule. Even productive and important lines of research can appear absurd. Several years ago, for example, a flurry of public attention surrounded the concept of "plant stress," which, when taken out of context, seemed to attribute personality characteristics to plants. However, plant stress is actually a critical area of research. Our understanding of how certain uniquely adapted plants resist freezing temperatures (Breton *et al.*, 2000), survive dehydration and drought (Hoekstra, Golovina, & Buitink, 2001; Bohnert, 2000), or thrive on excessively saline soil and water (Ruiz, 2001; Zhu, 2000), can be used to bioengineer

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standard crops to be less susceptible to these environmental stressors. The resulting improved agricultural productivity may be much welcome in light of potential negative pressures from global climate change and increasing population growth (Daily & Ehrlich, 1990; Serageldin, 1999).

In essence, science progresses on the basis of the best information available at the moment. For many of the issues that we wish to understand, this means that our understanding is necessarily incomplete and, as research continues, may be subject to revisions on the basis of new information. This situation is exemplified by recent epidemiological models of variant Creutzfeldt-Jakob (vCJD) disease, the human version of the so-called "mad cow" neurodegenerative disease. Although the cause of the disease has been associated with eating beef from cattle infected with bovine spongiform encephalopathy (BSE), other parameters of the disease have been more difficult to parse. Current models (Balter, 2001; Ghani *et al.*, 2002; Huillard d' Aignaux, Cousens, & Smith, 2001), presenting estimates about the number of people infected and the time lapse between infection and appearance of symptoms, show a certain amount of disagreement. Although it is sometimes necessary to base public policy decisions on such information, any actions taken on the basis of these interim models will most certainly need to be revised in the future when more information becomes available.

Public Perception and Awareness of Science

Despite the inherent uncertainty involved in scientific processes, and sometimes the conflicting public opinions that result, scientists themselves are often ranked high in public respect in many parts of the world. In the United States (US), for example, the public's perception of the prestige attributed to various professions ranked doctors and scientists as first and second, respectively, with scientists having gained points in recent years (Taylor, 1998). In Europe, by contrast, surveys indicate that such trust that exists in universities—homes to many research scientists—is considerably lower than trust in the medical profession, and has been eroded in recent years (European Commission, 2000). And even favorable views of scientists can run concurrently with views of the "mad scientist run amok," that science delivers unstable messages, or has a broader reach than the public would wish. (Each of these problems—and the Frankenstein parallels, the fears about implications of agbiotech company mergers [Joly & Lemarié, 1998], and the confusion about how science acquires and disseminates information—are all apparent in the debate on genetically modified foods.) Indeed, the issues of scientific fact and of public trust in scientists are thoroughly intertwined. But public trust is not solely dependent on a steady flow of assertions from scientists that may have to be changed later. Trust can also be built by showing the public the process of science itself—the nature of investigation and experimentation, as well as the drive to frame and answer useful questions about how the natural world functions.

By their own account, the public recognizes certain deficiencies in their understanding of science. For example, a survey from the National Science Foundation (NSF) (National Science Board, 2000), on the attitudes of adults in the United States concerning science, indicates that although 90% of adults are interested in science, only 17% feel that they are well informed about science. In describing their scientific knowledge, the individuals surveyed indicated that they knew approximately an equal amount about agricultural issues and space exploration, although this was considerably less than their knowledge of medical discoveries and environmental pollution. And, even though the 1990s witnessed an increase in the number of people able to define "molecule," "DNA," and "Internet," about 75% of adults in the United States still are unclear about the nature of scientific inquiry. The NSF survey also noted that some of the failures in communication between scientists, the media, and the public are rooted in scientists' distrust of the media and misplaced assumptions that the public was not interested. Moreover, there was also a discrepancy in the views that scientists and the public hold about the manner in which scientists work: Most people recognize the benefits derived from science, but non-scientists show a greater tendency than scientists to think that research results are affected by the researcher's personal values.

The foregoing discussion poses the following question: Is there a method by which we can change the public's perceptions, and give the non-scientist a better sense of what scientific discovery and scientific progress is all about? Perhaps if we made a greater effort to communicate and explain the process of scientific discovery, we could ultimately enhance the public's understanding of science and close the gap between the public's knowledge of science and the nature of science. One method that shows real promise in this regard is the exploration of a scientific controversy.

What Are Scientific Controversies?

Controversy exists wherever one party disagrees with another. It may be that modern controversies ignite faster and spread more widely than those in centuries past because the media is more developed now than then. And the border-free, self-published attributes of the Internet only serve to speed up the tempo and breadth of the debate.

We can understand a bit more about how controversy in science works by looking at different sorts of controversies that often require different types of information for their resolution. For instance, there are "decisional controversies," in which we must take action despite inadequate information—consider how the need to manage the foot-and-mouth disease epidemic in Britain conflicted with the absence of knowledge of the full extent of the epidemic (Keeling *et al*., 2001; Ferguson, Donnelly, & Anderson, 2001). There are "ethical controversies," in which the issues of debate are matters of morality, ethics, or preferences—consider the ethics of allowing access to the scientifically informative database about human genetics of the Icelandic population (Chadwick, 1999). And there are most certainly "informational controversies," in which the unknown is fully expected to be elucidated by further scientific research—consider the studies analyzing existence of stem cells in the brain (Gould *et al*., 1999; Kornack & Rakic, 2001).

The debate surrounding GMF includes all of these aspects of controversies. For example, decisions about how to deploy pest-resistant crops are being made even while research continues to study how to manage the evolution of the pest's response to the new challenge (Tabashnik, 2001; Gahan, Gould, & Heckel, 2001; Griffitts *et al*., 2001). Discussions about ownership of germ plasm as represented in seed stocks may lead to changes in what resources are available to individual scientists and to countries (Charles, 2001). And scientific exploration continues in efforts to resolve any number of unknown questions, including, for example, means to enhance the aroma of tomatoes (Lewinsohn *et al*., 2001) and nutritional quality of rice (Ye *et al*., 2000).

Scientific controversies as such are rarely clean and neat. Complications can always arise when facts that can clarify an issue arrive on the scene more slowly than the public's desire to know the truth. In these cases, there may be a temptation to address the absence of hard, scientific information with excessive speculation, the result of which can be a degradation of the trust between scientists and the public.

And while further research may well resolve controversies arising from a void of factual information, responses to decisional and ethical controversies are dependent on a number of ancillary factors. In attempting to resolve the issues, it is therefore important to recognize and invite input from the people whose lives could be affected by the decisions scientists and politicians ultimately make. It is similarly important to recognize that arguments purported to be based on scientific fact will not adequately address a controversy for which the real issues are ethical, moral, or matters of taste. Even though the use of scientific facts to support what are really emotional positions may sometimes succeed, resolution is more likely to succeed if the underlying issues are addressed openly (Sauer, 2001).

Ultimately, therefore, we need a dialogue between scientists and the public, which could be facilitated by engagement over a science controversy. A dialogue serves to inform policy decisions with a broad base of experiences and community needs. It also engages the public, so that they become more familiar with the issues and are able to adjust their opinions in response to new insight and progress in scientific understanding. This engaged interaction is more effective at promoting learning and understanding than the more passive information-recipient mode of learning (Bransford, Brown, & Cocking, 2000).

Challenges For Public Dialogue

In using controversy to promote scientific understanding, there are a number of challenges that one will encounter when trying to showcase the full range of scientific and policy debate, while at the same time promoting the participation of non-experts in resulting policy dialogues. Linn, Bell, and Hines (1999-2001) are exploring a means of addressing these challenges in the Web-based project "SCOPE: Science Controversies OnLine: Partnerships in Education," a portion of which is centered on the debate around the controversial issue of genetically modified foods (GMFs). The primary focus of SCOPE is on building online, knowledge-building communities and classroom activities centered around current scientific controversies. The Internet is favored as a medium for dialogue, as it promotes interactivity between scientists, science educators, students, and non-scientists, and povides access to a wide range of supporting material.

One challenge facing practitioners that would use scientific controversy as a means to promote scientific understanding is that knowledge evolves over time: "Currently accepted dogma" is a moving target, and its relationship to actual fact is dependent on the state of our scientific knowledge. In addition to conveying to those who are not research scientists the current best estimate of the truth, one also needs to convey the understanding that this estimate of reality may change, or may be dependent on certain assumptions undertaken during the research study.

Another challenge in exploring scientific controversies is that negative results are not as easy to publish in high-visibility journals, nor do they generate as much media or public response as positive results do. Part of the reason for this is that it is difficult to prove the complete absence of something, while it is far easier to demonstrate its positive occurrence, rare though it might be. For example, it is difficult to prove with complete certainty that taco shells containing traces of genetically modified corn are harmless—but as soon as a single case of harm were to be identified, it would become news. Consider also the study that showed a detrimental effect of *Bacillus thuringiensis* (Bt)-engineered pollen on caterpillars in a laboratory context (Losey, Raylor, & Carter, 1999), and some responses to the study (Hellmich *et al*., 2001; Oberhauser *et al*., 2001; Pleasants *et al*., 2001; Scriber, 2001; Sears *et al*., 2001; Shelton & Sears, 2001; Stanley-Horn *et al*., 2001; Zangerl *et al*., 2001) showing that there was no increased invasiveness of specific GMF crops in a given ecological context (Crawley *et al*., 2001). The first article, hinting at possible dangers, galvanized public debate and activated researchers to investigate. The second article by Crawley *et al.* (2001), suggesting the absence of harm on an equally important point, did not produce a similarly galvanizing effect. Such bias against reporting on "negative" rather than "positive" results has been found elsewhere (Koren & Klein, 1991).

Furthermore, even though controversy can be effective in gaining the public's attention and inciting action when needed, it can also oversimplify issues, stifle voices, and lead efforts into non-productive directions. The debate about the effect of Bt pollen on monarch butterflies highlights the problem of oversimplification—that is, that the science that makes up the real world can be much more subtle and complex than the scientific results produced from a single laboratory experiment. The discovery that Bt pollen is deleterious to captive caterpillars within a specific laboratory context (Losey, Raylor, & Carter, 1999) seems clear. And yet it is not otherwise clear that Bt pollen in an agricultural field would be more destructive than the pesticides used in the absence of pest-resistant Bt-engineered crops (Scriber, 2001). In fact, a larger view of the issue of refining methods for using Bt as part of a pest control strategy suggests that Bt could be very useful and less destructive than other pest-control methods (Pimentel & Raven, 2000).

In addressing controversy as part of an education process, one must also be aware that strong proponents of a particular position may not be terribly interested in contributing to an open debate. Groups favoring a particular perspective may aggressively push their own point of view without particularly inviting debate or challenge to that point of view.

In addition, the public often want simplicity. People like to see a clear "bottom line," a take-home message that summarizes whatever the published article or debate might be about. In such simplifications, many interesting and important nuances of the science can be lost.

Conclusion

As should be clear from the effects of the public's outcry about genetically modified foods, public response to a new technology can determine what aspects of that technology are implemented, how extensively the technology is introduced, and what directions future developments on that technology may take. Members of the public may not be in the research lab scrambling around working with transcription factors and protein expression arrays, or in the field assessing ecosystem dynamics, but they are nonetheless involved with science at several levels. The availability of public funds for research, the laws restricting certain sorts of research, and the marketplace acceptance of products all affect the course of science. What is needed, therefore, is a productive discussion among scientists, educators, media, and the public at large to alleviate misunderstanding and to get at the heart of the issues, especially the controversial issues. The SCOPE project by Linn, Bell, and Hines (1999-2001) is one step in this direction, for it is designed to bring to light the underlying assumptions or agendas in scientific issues, and it works to enable the readership to look at complex results in a realistic context.

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