What does citizen science accomplish?

Bruce V. Lewenstein
Cornell University

Prepared for meeting on citizen science, Paris, France, 8 June 2004
DRAFT: 27 May 2004

ABSTRACT

The terms "citizen science" and "citizen scientist" have at least three meanings: (1) the participation of nonscientists in the process of gathering data according to specific scientific protocols and in the process of using and interpreting that data; (2) the engagement of nonscientists in true decision-making about policy issues that have technical or scientific components; and (3) the engagement of research scientists in the democratic and policy process. Looking just at the first definition, proponents of citizen science argue that it engages nonscientists in the scientific process, making them direct participants in the creation of reliable knowledge about the natural world.

From an S&TS perspective, many statements in the preceding paragraph pose problems. What is meant by "engagement"? Can we distinguish between the "technical," "scientific," and "policy" components of a decision? How much social process is hidden by the phrase "specific scientific protocols"? What is meant by "the scientific process"? What constitutes "reliable knowledge"? What is the "natural world" and how does it differ from other conceptions such as the "social world"?

In this paper, I will use attempts to define the "outcome" of several specific citizen science projects at the Cornell Laboratory of Ornithology as a case for exploring the meanings of these various phrases. I will suggest that defining "success" for citizen science projects requires, in part, that the scientific community that supports citizen science must leave behind its Mertonian ideals about the independence of science and adopt instead S&TS-inspired conceptions of the social embeddedness of scientific knowledge.

What is "citizen science"?

What do we mean by "citizen science"? As reflective S&TS researchers, we are aware of the complexities of the terms. As used in projects like those run by birdwatchers and environmental monitors, "citizen science" means something like "making non-experts an integral part of the scientific process" (Bonney 1996, 2004; Krasny and Bonney 2004). Others, especially some leaders of the scientific community, use the term "citizen scientist" or "civic scientist" to refer to working scientists who participate actively in public debates on scientific and technological issues (Schneider 1993; Lane 1996). And finally, within the science studies community, Alan Irwin and others have used the term "citizen science" to mean something like "participation by non-experts in the governance of society when dealing with technically-based topics" (Irwin 1993, 1995, 2001).

The first and the third meanings, in particular, appear at first to be quite similar. They both depend on the emerging belief in "public engagement in science," on a commitment to linking public knowledge and expert knowledge in ways that productively draw on the strengths of different bodies of knowledge (Leshner 2003; House of Lords 2000; Miller 2001).

But there is a fundamental difference between the first two approaches and the third. The first approach, integrating non-experts into scientific work, is based on the "deficit model," the belief that "science" is an identifiable body of knowledge that one can learn (Wynne 1991; Ziman 1991). Once learned, it can be used to contribute to personal decisions, to community, civic, or political decisions, or simply to one's enjoyment of life and culture (Shen 1975). But those contexts – especially the communal or political ones – are seen as independent of science, as spaces based in fundamentally *separate* sets of knowledge, following Mertonian ideals about the independence of science (Merton 1973). Science, in the deficit model conception, is ontologically different than other kinds of knowledge. The deficit model arose as the scientific community addressed its belief that more "public understanding of science" is necessary, both for the altruistic reason that better understanding of science leads to a better society, and because of the more self-serving (but probably mistaken) belief that better understanding necessarily leads to better material support for the scientific enterprise and the institutions of science (Lewenstein 1992; Greenberg 2001; Royal Society 1985).

To reduce the deficit – or, in another frequent phrase, to address the "problem" of "science literacy" – the scientific community has regularly since World War II sponsored many activities intended to "im prove" the public understanding of science. Although the full definitions of "scientific literacy" included nuanced understanding of the scientific process and scientific institutions (Miller 1983; Evered and O'Connor 1987; Bauer 1992; Shamos 1995; Holton 1983; Ziman 2000; Shortland 1987), many people focused on specific areas of factual knowledge, especially simplistic questions about, for example, the relative size of electrons, atom, and molecules; the value of antibiotics against viruses or bacteria; and the simultaneous presence of humans and dinosaurs in geologic time (Evered and O'Connor 1987; National Science Board 1991).

In the United States, as one component of the effort to address the problem of science literacy, the scientific community in the 1980s engaged in a review of science education (Project 2061 1989). A crucial element of that review was a growing understanding, by looking at both empirical studies and theoretical work in psychology and learning, that traditional approaches to teaching were often ineffective. In particular, didactic, lecture-based presentations of technical information often led to students memorizing particular "facts," but not understanding the scientific process or the interconnections between findings. Instead, educators were encouraged to "engage" the students in "inquiry-driven," often "hands-on," learning activities (National Research Council 1996; American Association for the Advancement of Science 1993). Frequently, these exhortations to engagement included the suggestion that students engage in scientific experiments, to understand how science "really" worked. The best scenario, some educators believed, would be for "student-scientist partnerships," in which students would provide the data that scientists needed to do their own, "real" science (Ross and Harnik 2003; Tinker and Barstow 1997; Cohen 1997). Such projects, sometimes called citizen science projects, would fully engage students in the scientific process, yielding benefits both to science and to the students (Bonney and Dhondt 1997; Trumbull et al. 2000; GLOBE 2004).

The second approach to or meaning of citizen science, in which expert scientists exercise an obligation to participate in public affairs, also clearly depends on a deficit model, one that separates scientific knowledge from other bodies of knowledge. It is precisely that separation that requires the scientist to bring his or her expertise to public policy decisions that have a technical component, argued the proponents of these activities (National Science Board 2000). Again, the proponents used the language of "engagement" to describe the role they believe that scientists should play in the policy arena (Lane 1996; Schneider 1986; Leshner 2003).

The third meaning of citizen science, however, draws on a very different ontological view of science. The third meaning emphasizes the participation of non-experts in governance, drawing heavily on the work of historians and sociologists of science in the 1980s and 1990s. The crucial contribution of this third meaning is the recognition of the fundamental importance of bodies of knowledge outside the formal structures of organized science (Cooter 1984; Shinn and Whitley 1985; Irwin and Wynne 1996). To sociologists of science and others in the science studies community, the essential socially-constructed nature of consent about what constitutes expert knowledge is well-understood. In the particular context of discussions of public understanding of science, the idea was perhaps most famously demonstrated in Brian Wynne's study of the sheepfarmers of Cumbria. There we learned that sheepfarmers had both insights into technical knowledge (about, for example, the unevenness of contamination from rainfall runoff as a result of the local effects of hillsides and gullies and pools, or how variations in soil type might affect cesium uptake) and relevant knowledge about other aspects of the sociotechnical ensemble (about the routines of marketing lambs, for example) that the formally-authorized "experts" did not have; yet those alternative insights were absolutely critical to the socially-embedded decisions on supposedly "technical" issues that the experts were insisting on making (Wynne 1989, 1996).

Several key advocates of this third approach to citizen science have been advisors to public policy discussions about citizen science and public engagement, notably Alan Irwin and Brian Wynne (Irwin 2001; House of Lords 2000). But while those policy discussions have led to much commitment to public discussion, it is not clear that they have fully acknowledged the inherent conflict between the different ontologies that underly different definitions of "citizen science." The first approach argues that science is a distinct body of knowledge separate from other bodies of knowledge, and that this separate body of knowledge has a higher status because of a greater fidelity with Nature and Truth. The second approach, though, questions the status of "science" as a separate category. Instead, it highlights the degree to which all knowledge is socially-constructed and makes sense only when situated in particular contexts and with reference to information and knowledge coming from many sources, not simply from the formalized mechanisms of modern science. (I should note that the inherent conflicts are beginning to be acknowledged. When the British government undertook a public consultation exercise on genetically-modified crops, for example, it discovered that it had to abide by the public sense that GM crops should not be allowed in the UK. Similarly, an editorial in *Nature* has warned about the challenge for science of dealing with democracy (Anon. 2003; GM Nation 2003).)

So the question facing the analyst of "citizen science" is to understand how the conflicting meanings can co-exist. Are there different conceptions of "citizen" at work? Difference conceptions of "science"? What are the fundamental assumptions and goals of citizen science, and can they be reconciled?

In what follows, I will present some observations from my own participation in a particular set of citizen science projects in an attempt to address this question. I will use the attempt to define "success" in these projects as on opportunity for identifying goals and achievements.

The cases: "Citizen Science" at the Cornell Laboratory of Ornithology

The Cornell Laboratory of Ornithology (CLO) is an independent unit of Cornell University, and serves both as a research center on issues of conservation and bird biology, and as a major site for amateur birdwatchers. It has a long history of working with birdwatchers to gather systematic data on bird populations. In 1987, working collaboratively with a Canadian bird observatory, it created "Project FeederWatch" (PFW) In this project, which continues to operate, birdwatchers observe their feeders during the winter months, following a specific protocol for how to count the number and species of birds that visit the feeders. The data are submitted to CLO, and become the scientific database on winter bird populations that ornithologists use to track and model bird population variations.

Beginning in the early 1990s, CLO began using research and education grants from the U.S. National Science Foundation to test the value of PFW and other "cooperative research projects" as an educational tool for addressing both formal (in-school) and informal (out-of-school) science education. In the process of building these projects, the CLO staff began to use the label of "citizen science" to describe them. There was no particularly deep thought given to the label – it seemed to describe the activities and provided a useful label for a variety of projects that were intended to extend the PFW model (Rick Bonney, personal communication).

By the mid- to late-1990s, the PFW model had been extended to several new projects. Among those were:

- Classroom BirdWatch (CBW) is a formal curriculum for elementary schools and middle schools that uses PFW as a vehicle for teaching students about birds, the scientific process, and other activities.
- Project PigeonWatch (PPW) is one of a suite of projects directed toward city residents; participants observe the size, make-up, and mating behaviors of pigeon flocks to gather data regarding the maintenance of human-created color patterns among pigeons even after they have returned to the wild.
- The Birdhouse Network (TBN) involves observing the date when cavity-nesting birds first lay eggs, and then watching the development of the clutch as it fledges.

Today, the CLO citizen science porfolio includes at least 10 different projects, some overlapping, some focusing on specific species, others on specific behaviors or ecological settings (Cornell Laboratory of Ornithology 2004; Krasny and Bonney 2004, Bonney, 2004 #4258).

Typically, a CLO citizen science project has the following elements: CLO researchers identify a research question that requires data gathering on a scale that cannot be accomplished by individual researchers or small research teams. They design a research protocol and create a "research kit" with instructions and supporting materials. A crucial element is the data-collection form; it must be easy-to-use, yet include enough information for scientists to test relatively complex hypotheses. In the early years, the materials were entirely printed; today, they are often available primarily online, especially the data-collection forms. Participants are recruited, sometimes through CLO's own membership, sometimes through other birding organizations (such as local Audubon chapters), sometimes through schools, sometimes through public announcements and publicity (when one project was mentioned on a major nationwide morning news broadcast, the CLO received nearly 80,000 phone calls in the following hours and days). Projects range from a single weekend or short set of observations to full seasons of observations. Data are submitted to the CLO by mail or Internet. Results are posted online, and various publications are sent to project participants to keep them informed of project progress. Formal scientific publications are submitted to peer-reviewed journals; while these publications acknowledge the role of project participants, they list as authors only the professional researchers analyzing the data.

Since 1995, I have served as evaluator for various CLO citizen science projects. My role has been to establish metrics for assessing the ability of the projects to achieve their goals, especially insofar as they could address issues of "science literacy" or "public understanding of science." I was trying to use what I knew about public understanding of science to help frame meaningful questions about what it was reasonable to assess regarding the projects' success. I approached these projects purely as a participant, not as an S&TS observer or analyst; I did not take "field notes" or record reflexive observations about "science," "citizenship," or related topics. Thus my comments on these issues are entirely retrospective and rely greatly on my own reinterpretation of my activities and the formal reports I have provided to the CLO staff.

Yet I would be wrong to leave the impression that the possibility of doing an S&TS analysis of citizen science had not occurred to me. It was obvious, for example, that "bird watching" and "science" were not necessarily synonymous. It was also true that although the project materials attempted to show the idealized "scientific process" (create a hypothesis, design an experiment, gather data, test the hypothesis, draw a conclusion), the actual activities were both less complex (in many cases, participants were given fully-created research protocols, which limited their involvement in creating the hypothesis) and more complex (many participants learned to create their own questions, and in recent years the possibility for doing that has been designed into the projects) than the idealized process would suggest. Nor was it clear to me how one could distinguish between "scientists" and "citizens" when both were involved in many of the same steps in the process.

Thus I was pleased when Florian Charvolin, a French researcher, proposed studying citizen science as a site where the very definitions of science were at stake.

Defining success, 1: Redefining "science"

Before I began participating in CLO projects, the evaluations consisted largely of assessing participants' satisfaction with project materials. Telephone and mail surveys asked about the ease of use of the materials, specific project steps that were difficult or confusing, and overall participant satisfaction. There were essentially no questions about learning outcomes or the relationship of citizen science projects to broader scientific issues.

Our first goal was to identify changes in attitudes and knowledge achieved by project participants. But attitudes and knowledge about what? We realized that participants were learning about birds, about environmental issues, and about science. But, because the focus was on *birds*, we wondered if they would realize that they were learning about the environment and science. Thus, for The BirdHouse Network, we designed a series of questions addressing both attitudes and knowledge about birds, environment, and science. The questions about science were drawn largely from the U.S. National Science Foundation's biannual studies of public attitudes and knowledge about science (National Science Board 1991, 1993, 1996, 1998, 2000), as we wished to compare citizen science participants with standard national measures. We were, of course, acutely aware of the many criticisms that have been made of the NSF data, which are the archetypal "deficit model" measures. They are simplistic, over-interpreted, and largely meaningless to the ways that people actually interact with scientific or technical knowledge (Wynne 1995; Bauer and Schoon 1993; Bauer, Petkova, and Boyadjjewa 2000; Roth and Lee 2002). Yet they provided the only well-established metric for assessing how this particular project was doing. In an idealized world, all worthwhile projects are supported; in the real world, some method is needed for deciding which projects are worthwhile. We did focus on the NSF questions that address questions of scientific process (such as open-ended questions that ask people to define what means to study something "scientifically"), rather than simple factual knowledge questions.

We sent surveys to project participants before they received project materials, and then again at the end of the project season. The results (Brossard, Lewenstein, and Bonney 2000)showed that attitudes towards birds, the environment, and science changed little – mostly because the participants were already at the "high" end of the scales; in other words, the self-selected participants in these projects already had very good attitudes toward birds and science and already considered themselves environmentalists. The project had little opportunity to change those attitudes. The knowledge scales showed that participants learned about birds. However, they learned little about science; in retrospect, we realized that the project materials did not emphasize that they were participating in a scientific activity, and thus participants did not connect their birdwatching with "science."

From an S&TS perspective, it is that final observation which is both the most obvious and most important. As the work of Wynne and others has shown, "science" as a category has little meaning in the lives of nonscientists. Citizen "science" of the sort provided by CLO projects is not really about science, but about engaging in a variety of activities involving the natural world and drawing meaning from those activities. Those meanings may involve self-improvement (increased knowledge), pleasure (spending time outdoors), family support (engaging in collective activities), and so on. Though "citizen science" as a description of activities for nonscientists is often used as if the boundaries of science are clear, in practice the activities of participants fit within no easily-demarcated boundaries.

Defining success, 2: The social matrix

This revised understanding of what citizen "science" achieves was reinforced from the findings of a an NSF project called "Parents Involved/Pigeons Everywhere" (PIPE). This project was funded under a program designed to increase parents' involvement in their children's science education. The plan was to use an existing CLO project – Project PigeonWatch – as an opportunity for urban (often minority) parents to become engaged in their children's learning. The program was designed to address a social issue: the uneven achievement of American minority students in formal schooling. "Science" was simply a vehicle for achieving a broader social interest, not an end in itself.

Yet even the goal of parental involvement was not necessarily achieved (Lewenstein 2001, 2004). PIPE proceeded by developing workshops for "leaders" (parents, grandparents, group leaders, etc.), who would learn about PPW and then encourage families to observe pigeon flocks and report their data back to CLO. These workshops were often held at science museums or community centers. As evaluator, I attended a number of these workshops. One of the most striking findings was the frequent *lack* of child-parent interaction. At several of the workshops, I saw children sitting together, actively looking at pigeon flocks, counting the numbers of pigeons of different colors, recording the data on the appropriate sheets. The parents – usually mothers, though occasionally a father – would sit or stand to the side, talking among themselves. Their conversations rarely had to do with pigeons, or birds, or indeed anything related to the day's activities. They were the normal conversations of neighbors: talks about activities at the school, recent neighborhood events, meals, the comings and goings of neighbors and friends.

The key insight was that, for these low-income, urban, minority parents, a chance to stand and talk was a rare event. Asked about the PIPE project, they expressed pleasure at it, and gave the response that they knew the questioner wanted: they were happy because they were helping their children with science. But the observations suggested that their real pleasure was at the opportunity for unpressured social time. Although we do not have data to test this idea, I believe that children and parents in the future would remember the PIPE workshops fondly – they would recall with pleasure having spent a day labeled "science" with their family, though they might not recall any specific learning or interaction.

From the perspective of program managers operating in a traditional "deficit model" mode, spending "science education" funds to promote social gathering does not appear to be a successful program. But the S&TS perspective recognizes that all "science" takes place in a social matrix; if promotion of social and family cohesion is defined as a good, then the PIPE program was a "success," regardless of the "science" outcome. This finding is particularly important in the context of "citizenship," for it suggests that being a "citizen science" is as much about being a citizen as it is about contributing to science, per se. In this sense, this finding addresses issues raised by Florian Charvolin in his studies of birdwatchers in France and the United States (Charvolin 2002, 2002). Charvolin is interested in the interactions of political visions of citizenship with the activities that birdwatchers engage in as they participate in collective acts of data-gathering. For him, participating in citizen science is an act of citizenship, but he is still focused on the "science" aspect of the project. My observations suggest that we can push this idea even further, and highlight the "citizen" component without regard to the "science" element.

Defining science, 3: Contributing to technical knowledge

Setting aside the "science" outcome is key to redefining the "success" of the CLO projects. One of the goals – indeed, one of the defining characteristics – of citizen science projects is to contribute to "real" science. As S&TS scholars have demonstrated many times, scientific knowledge exists only insofar as it is a communally-held, "public" knowledge validated both by publication and then by subsequent citation (Garvey 1979; Ziman 1968; Merton 1973; Hagstrom 1965). By that measure, CLO projects have succeeded (at least to the stage of publication), leading to peer-reviewed published papers on bird population distributions, the effect of environmental change on breeding success, the spread of infectious diseases in wild animal populations, and how acid rain affects bird populations (Bonney 2004).

Yet a significant part of the rhetoric of citizen science is the engagement of participants in the full spectrum of scientific activity. CLO staff acknowledge that, for the most part, citizen science projects come with pre-determined hypotheses and scientific protocols, but they also believe that some of their newer projects (especially the data and tools collected on eBird, www.ebird.com) are sufficiently flexible to allow participants to design their own questions. Citizen science projects at CLO also often involve newsletters or other reports so that participants can "publish" their results (indeed, I was one of the active proponents for adding such an activity to Classroom FeederWatch).

The problem is that only a small percentage of citizen science participants actually submit their data to the database (Rick Bonney, personal communication). In Project FeederWatch, the original and in some ways the easiest full project, about half of the roughly 15,000 people each year who pay money for PFW materials actually follow through with submitting data. In some projects, such as PigeonWatch or Classroom FeederWatch, the numbers are much smaller. Thus, by the measure of participating in the *full* spectrum of scientific activity, including the defining characteristic of sharing information with other researchers, most "citizen scientists" in CLO projects fail.

Nonetheless, the CLO citizen science projects clearly engage many people, most of whom consider their participation a success, many of whom willingly pay money for the privilege of participating, many of whom repeatedly come back to CLO (in person or through the mail or Internet) to participate again. The CLO's citizen science evaluation reports are full of quotes from participants describing the projects as among the most exciting, well-done, appealing projects they have participated in.

In the sections above, I suggested that "success" had to be redefined away from changes in attitudes or knowledge of the sort that the deficit model calls for, and that the wider range of outcomes (including general social strengthening) had to be considered. This final point suggests that a project does not even have to be completed to be successful. The analogy to "citizenship" might be that there are many possible ways to be a productive citizen – engaging in debate, contributing to a cause, writing a letter to the editor, etc. Voting, sometimes spoken of as the *sine qua non* of citizenship in a modern democracy, is in fact often ignored, even by people who are actively engaging in collective social action in other ways. Not only are many outcomes possible for citizen science, but some of them appear radically different from "citizenship."

Conclusion

The comments above are only intended as a first attempt to a reflexive understanding of what citizen science can accomplish. But I believe the observations suggest that there need not be an inherent conflict between the deficit model underpinnings of some "citizen science" definitions and the more contextual, sociologically-inspired definitions favored by those in S&TS. Instead, it might be more appropriate to understand that the rhetoric of citizen science may assume a deficit model, but the actual achievements of student-science partnerships and similar projects are best understood in the contextual, real-world way that S&TS scholars have long understood the activities of those who call themselves "scientists." In that way, I suppose, "citizen scientists" really have achieved the goal of being just like "real" scientists.

Moreover, the observations above suggest that participating in citizen science is not really about science at all, but is primarily a means of achieving greater membership in the social world that helps constitute the body politic. This finding, too, strengthens our understanding of essential social-embeddedness of science, both as a human activity and ultimately as a body of knowledge.

ACKNOWLEDGEMENTS

I thank Rick Bonney of the CLO for inviting me to participate in the CLO's citizen science projects and keeping me involved for many years. Dan Cullen, Dominique Brossard, Joanna Radin, and Stephanie Thompson have served as students or employees working on citizen science projects and I thank them for their help. Judy Kass at the American Association for the Advancement of Science ensured my participation in the PIPE project. Many other staff at AAAS, at CLO, and at other institutions have provided valuable insights into the citizen science projects.

REFERENCES

American Association for the Advancement of Science. 1993. *Benchmarks for Science Literacy*. New York: Oxford University Press.

Anon. 2003. Dealing with democracy. *Nature* 425 (6956):329.

Bauer, Henry H. 1992. *Scientific Literacy and the Myth of the Scientific Method*. Urbana and Chicago: University of Illinois Press.

Bauer, Martin W., K Petkova, and P Boyadjjewa. 2000. Public knowledge of and attitudes to science - alternative measures. *Science, Technology & Human Values* 25 (1):30-51.

Bauer, Martin W., and Ingrid Schoon. 1993. Mapping Variety in Public Understanding of Science. *Public Understanding of Science* 2 (2):141-155.

Bonney, Rick. 1996. Citizen Science: A Lab Tradition [Project FeederWatch, FeederWatch in the Classroom, Project Tanager, Project PigeonWatch, Cornell Nest Box Network]. *Living Bird*, August, 7-15.

———. 2004. Understanding the process of research. In *Creating Connections: Museums and the Public Understanding of Current Research*, edited by D. Chittenden, G. Farmelo and B. Lewenstein. Walnut Creek, CA: Altamira Press.

Bonney, Rick, and Andre Dhondt. 1997. FeederWatch: An Example of a Student-Scientist Partnerhip. In *Internet links for science education : student-scientist partnerships*, edited by K. Cohen. New York/London: Plenum.

Brossard, Dominique, Bruce Lewenstein, and Rick Bonney. 2000. Scientific Knowledge and Attitude Change: The Impact of a Citizen Science Project. Paper read at National Association for Research on Science Teaching, April, at New Orleans.

Charvolin, Florian. 2002. Critical accounts of a successful program in public understanding of science: Project Feederwatch as citizen science. Ithaca, NY: Presented to S&TS Colloquium.

———. 2002. Identifying the bird/identity of a member of the Rhône-Alpes Ornithological Society: The problem of "distance link" between social activity and relationship to Nature, edited by J. Jabras. Paris.

Cohen, Karen C. 1997. *Internet links for science education : student-scientist partnerships*. New York ; London: Plenum Press.

Cooter, Roger. 1984. *The Cultural Meaning of Popular Science: Phrenology and the Organization of Consent in Nineteenth Century Britain*. Cambridge: Cambridge University Press.

Cornell Laboratory of Ornithology. 2004. *The Power of Citizen Science* 2004 [cited 25 May 2004]. Available from http://www.birds.cornell.edu/LabPrograms/CitSci/index.html.

Evered, David, and Maeve O'Connor, eds. 1987. *Communicating Science to the Public*. Chichester: John Wiley.

Garvey, William D. 1979. *Communication: The Essence of Science--Facilitating Information Exchange among Librarians, Scientists, Engineers and Students*. Oxford/New York: Pergamon Press.

GLOBE. 2004. *The GLOBE Program: An Exciting, Worldwide, Hands-on Education and Science Program* 2004 [cited 25 May 2004]. Available from www.globe.gov.

GM Nation. 2004. *GM Nation website* 2003 [cited 25 May 2004]. Available from http://www.gmnation.org.uk/.

Greenberg, Daniel S. 2001. *Science, money, and politics : political triumph and ethical erosion*. Chicago: University of Chicago Press.

Hagstrom, Warren. 1965. *The Scientific Community*. New York: Basic Books.

Holton, Gerald James. 1983. Science Literacy (special issue). *Daedalus* 112:1-251.

House of Lords. 2000. Science and Society. London: UK House of Lords.

Irwin, Alan. 1993. *Science, citizenship, and modernity: living with environmental threat*. sound recording.

———. 1995. *Citizen science : a study of people, expertise, and sustainable development*. London ; New York: Routledge.

———. 2001. Constructing the scientific citizen: Science and democracy in the biosciences. *Public Understanding of Science* 10 (1):1-18.

Irwin, Alan, and Brian Wynne, eds. 1996. *Misunderstanding Science? The Public Reconstruction of Science and Technology*. Cambridge: Cambridge University Press.

Krasny, Marianne, and Richard Bonney. 2004. Environmental education through citizen science and participatory action research. In *Environmental Education or Advocacy: Perspectives of Ecology & Education in Environmental Education*, edited by E. A. Johnson and M. J. Mappin. New York/Cambridge: Cambridge Univ. Press.

Lane, Neal F. 1996. Editorial: Civic Science. *Science* 271 (5252):1037.

Leshner, Alan I. 2003. Public Engagement with Science. *Science* 299:977.

Lewenstein, Bruce. 2001. PIPE Evaluation Report, Year 2: 1999-2000. Ithaca, NY: Seavoss Associates Inc.

———. 2004. PIPE Final Evaluation Report. Ithaca, NY: Seavoss Associates Inc.

Lewenstein, Bruce V. 1992. The Meaning of 'Public Understanding of Science' in the United States

After World War II. *Public Understanding of Science* 1 (1):45-68.

Merton, Robert. 1973. The Normative Structure of Science. In *The Sociology of Science: Theoretical and Empirical Investigations*, edited by N. Storer. Chicago: University of Chicago Press.

Merton, Robert K. 1973. *The Sociology of Science: Theoretical and Empirical Investigations*. Edited by N. W. Storer. Chicago: University of Chicago Press.

Miller, Jon D. 1983. Scientific Literacy: A Conceptual and Empirical Review. *Daedalus* 112 (2):29-48.

Miller, Steve. 2001. Public understanding of science at the crossroads. *Public Understanding of Science* 10 (1):115-120.

National Research Council. 1996. *National Science Education Standards*. Washington: National Academy Press.

National Science Board. 1991. Public Science Literacy and Attitudes Towards Science and Technology. In *Science & Engineering Indicators--1991*, edited by National Science Board. Washington: U.S. Government Printing Office.

———. 1993. Science and Technology: Public Attitudes and Public Understanding. In *Science & Engineering Indicators--1993*, edited by National Science Board. Washington, D.C.: U. S. Government Printing Office.

———. 1996. Science and Technology: Public Attitudes and Public Understanding. In *Science & Engineering Indicators--1996*. Washington, D.C.: U.S. Government Printing Office.

———. 1998. Science and Technology: Public Attitudes and Public Understanding. In *Science & Engineering Indicators--1998*. Washington, D.C.: U.S. Government Printing Office.

———. 2000. Communicating Science and Technology In the Public Interest. Washington, DC: National Science Board.

———. 2000. Science and Technology: Public Attitudes and Public Understanding. In *Science & Engineering Indicators--2000*. Washington, D.C.: U.S. Government Printing Office.

Project 2061. 1989. *Science for All Americans*. Washington, D.C.: AAAS.

Ross, Robert M., and Paul G. Harnik. 2003. Student-Scientist Partnerships in Geosciences [special issue]. *Journal of Geoscience Education* 15 (1).

Roth, Wolff-Michael, and Stuart Lee. 2002. Scientific literacy as collective praxis. *Public Understanding of Science* 11 (1):33-56.

Royal Society. 1985. *The Public Understanding of Science*. London: Royal Society.

Schneider, Stephen H. 1986. Both Sides of the Fence: The Scientist as Source and Author. In *Scientists and Jornalists: Reporting Science as News*, edited by S. M. Friedman, S. Dunwoody and C. L. Rogers. New York: The Free Press.

———. 1993. Is the "Scientist-Advocate' an Oxymoron. Paper read at American Association for the Advancement of Science, at Boston, MA.

Shamos, Morris. 1995. *The Myth of Scientific Literacy*. New Brunswick, N.J.: Rutgers University Press.

Shen, Benjamin S. P. 1975. Science Literacy and the Public Understanding of Science. In *Communication of Scientific Information*, edited by S. Day. Basel: Karger.

Shinn, Terry, and Richard Whitley, eds. 1985. *Expository Science: Forms and Functions of Popularisation*. Vol. 9, *Sociology of the Sciences*. Dordrecht/Boston/Lancaster: D. Reidel.

Shortland, Michael, ed. 1987. *Scientific Literacy Papers*. Oxford.

Tinker, Robert, and Dan Barstow, eds. 1997. *Proceedings of the National Conference on Student & Science Partnerships*. Cambridge, MA: TERC.

Trumbull, Deborah, Rick Bonney, Derek Bascom, and Anna Cabral. 2000. Thinking Scientifically during Participation in a Citizen-Science Project. *Science Education* 84:265-275.

Wynne, Brian. 1989. Sheep Farming After Chernobyl: A Case Study in Communicating Scientific Information. *Environment Magazine* 31 (2):10-15, 33-39.

———. 1991. Knowledges in Context. *Science, Technology & Human Values* 16 (1):111-121.

———. 1995. Public Understanding of Science. In *Handbook of Science and Technology Studies*, edited by S. Jasanoff, G. E. Markle, J. C. Petersen and T. Pinch. Thousand Oaks, Ca.: Sage.

———. 1996. May the sheep safely graze? A reflexive view of the expert-lay knowledge divide. In *Risk, Environment and Modernity: Towards a New Ecology*, edited by S. Lash, B. Szerszynski and B. Wynne. London: Sage.

Ziman, John. 1991. Public Understanding of Science. *Science, Technology & Human Values* 16 (1 (Winter)):99-105.

———. 2000. *Real Science*. Cambridge: Cambridge University Press.

Ziman, John M. 1968. *Public Knowledge: An Essay Concerning the Social Dimension of Science*. Cambridge: Cambridge Univ. Press.