Professional Development Needs and Outcomes for Education-Engaged Scientists: A Research-Based Framework

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ABSTRACT

Involvement of scientists in education is essential to strengthen quality and access to US science education at the K-12 and higher levels. Yet little research evidence exists to help practitioners understand scientists' education and outreach interests, beliefs, and motivations, and the barriers that must be addressed to involve them effectively. The ReSciPE Project (Resources for Scientists in Partnership with Education) has offered professional development workshops and resources to a wide audience of working scientists who undertake individual or institutional education and outreach activities. While seeking to increase the effectiveness of these "education-engaged scientists," the project also conducted research on scientists' involvement in education. We report findings from qualitative analysis of 30 in-depth interviews and propose a comprehensive framework for addressing scientists' needs for professional development in this domain, placing these findings in context of national needs and efforts to engage scientists in education.

INTRODUCTION

In recent years, funders and institutions have asked scientists to become more involved in communicating the "broader impacts" of their work with the public (NASA, 1996; NSF, 1997, 2001a, 2002, 2003; Dolan et al., 2004; Fraknoi, 2005). Eminent scientists and educators have called for scientists to participate in K-12 education (Alberts, 1991; Bybee, 1998; Colwell and Kelly, 1999; NRC, 1996). Many scientists are also motivated by personal, altruistic, and societal reasons to contribute to public science literacy and school science education (Wier, 1993; Falk and Drayton, 1997; Andrews et al., 2005). Scientists' contributions of materials, expertise, and enthusiasm have the potential to improve science education nationally-but these contributions must be mobilized effectively to realize genuine benefits and sustain scientists' involvement.

Scientists can contribute to education in many ways: as advocates and spokespersons; as experts on science and the scientific process; as people with exciting, true stories of exploration and discovery; as providers of data and facilities; and as role models for students and teachers (Bybee and Morrow, 1998; Morrow, 2000; Bower, 1996; NRC, 1996). These roles may be carried out at varying levels of involvement, in formal and informal education, and on behalf of students, teachers, or leaders of systemic change.

However, to contribute effectively in these roles, scientists need crucial skills and understanding (Laursen, 2006; Leshner, 2007). Scientists tend first to offer their content expertise, yet research topics are not always appropriate for K-12 science. Scientists may be more comfortable in high schools than at lower grades, where children may be reached before losing interest in science (Alberts, 1991). Cultural and language differences can inhibit effective interaction of scientists with educators (Bower, 1996; Morrow 2003; Richmond, 1996; Tanner, Chatman, and Allen, 2003). In sum, scientists need professional development to make their education work both effective and rewarding. Indeed, a poor experience with outreach can deter further participation (Andrews et al., 2005).

The ReSciPE Project (Resources for Scientists in Partnership with Education) grew out of the recognition that effective participation in education or outreach (E/O) work is a new professional expectation for most scientists. While a few programs have addressed broad E/O participation (Morrow and Dusenberry, 2004) or training for specific programs (e.g., SEP, 2007; CRS, no date), in general, professional development on education for working scientists has been rare. Between 2004 and 2007, ReSciPE has given 16 workshops on "Scientific Inquiry in the Classroom" to over 350 scientists and educators at laboratories, universities, and conferences across the US. The project also developed the ReSciPE Book, a selective online collection of annotated resources (ReSciPE, 2005).

In addition to offering professional development to support scientists' E/O work, ReSciPE has drawn on workshop participants as a source of research data. To date, little information from research and evaluation has been available about scientists' interests, needs, motivations, and barriers to participating in education. Andrews, et al. (2005) reviewed the literature and found that most information on E/O participation came from the service learning community, which includes science but does not represent professional scientists at large. These authors also report findings from their own small study about scientists' motivations to participate in outreach and the benefits and costs of participating. However, their data were gathered prior to the present emphasis on broader impacts, before E/O involvement was a common, funder-leveraged, professional obligation of scientists. Thus their conclusions may not apply in the context of scientists' participation today.

Storksdieck et al. (2002) surveyed over 1100 amateur astronomers, two thirds of whom were involved in E/O. Their data provide a broad snapshot of the E/O activities and perceived needs of volunteers in one discipline. Mathews, Kalfoglou and Hudson (2005) studied academic geneticists' views of scientists' role in public debate on genetic research and technologies. Respondents felt scientists should be more involved in communicating with the public and setting policy, but felt "ill-equipped and unsupported" to participate.

Only a few E/O programs involving scientists have examined their scientist participants as well as their audience. Studies of a general scientist population emphasize the benefits gained from E/O participation or desire to remain involved (Messmore, 1996; Tanner, 2000; Beck et al., 2006). A paper by Gibbs and Berendsen (2007) is unusual in examining some measures of scientists' effectiveness in classroom partnerships. Most common in the literature are arguments for scientists' involvement and descriptions of specific programs (Munn et al., 1999; Koehler, Park and Kaplan, 1999; Dolan et al., 2004; Evans et al., 2001; Feldstein and Benner, 2004).

Several studies examine graduate student scientists' involvement in E/O, primarily through NSF-funded GK-12 programs. These studies address the benefits and costs of participating in organized K-12 classroom outreach (Gilmer, Granger and Butler, 2005; Mitchell et al., 2003; Stamp and O'Brien, 2005; Thompson, et al., 2002; Trautmann et al., 2002; Trautmann and Krasny, 2006; Busch and Tanner, 2006; Laursen et al., 2007). Some address the risks to graduate students of declaring their educational interests in research-oriented science departments (Thompson et al., 2002; Thiry, Laursen and Liston, 2007), the long-term career impacts of participation (Laursen, Thiry, and Liston, 2008), or outcomes for undergraduate scientists (Bruce et al., 1997). While this evidence is informative, some issues particular to young scientists may not apply in career settings, and at present access to intensive programs like these is very limited. Thus, while it is clear that E/O work as part of graduate education is professionally formative, it is both unrealistic and painfully slow to wait for science graduate programs to address all scientists' E/O training needs.

This paper reports findings from a research-with-evaluation study conducted by the ReSciPE Project. We briefly describe the workshops attended by study participants, and the study methods and samples. Our research findings are organized in a three-stage framework outlining scientists' professional development needs in education.

CONTEXT FOR THE STUDY: OVERVIEW OF ReSciPE WORKSHOPS

Format and Audience - The standard workshop was half a day. Workshops were hosted by geoscience organizations in atmospheric science, climatology, geology, astronomy, and limnology/ oceanography, and by multidisciplinary groups. Workshops held at professional meetings drew participants from varied institutions and career stages, while those at specific institutions generated local esprit de corps and promoted participation in local programs.

Inquiry as a Topic of Focus - Students should learn science in an authentic manner, as science is really done. The National Science Education Standards (NSES) identify three goals of science education for all students: to learn important principles and concepts of science ('learn science'), to develop the procedural skills and critical reasoning skills needed to carry out a scientific investigation ('learn to do science'), and to understand the nature of science as a human activity to construct knowledge ('learn about science') (Olson and Loucks-Horsley, 2000). These goals emphasize the process of building scientific knowledge-posing a question, carrying out an investigation, critiquing and communicating its results-as much as its existing facts and concepts. The term inquiry refers to this scientific process as applied to education, where inquiry is both a strategy for 'learning science' and a subject of study itself, when 'learning to do' and 'learning about' science. Thus ReSciPE chose "scientific inquiry in the classroom" as the topic for an initial professional development experience for scientists. Inquiry is crucial to national science education goals, and it is both understood by and engaging to scientists as a way to contribute.

Workshop Agenda - Presenters used a mix of activities to model inquiry teaching and learning approaches. An opening presentation described the NSES framework on inquiry and summarized evidence from education research that supports inquiry methods (Bransford et al., 1999). Then, using collaborative, hands-on activities, scientists saw how students can 'learn about' and 'learn to do' science. Spirited arguments about the workings of a sealed "black box" (FOSS, no date) showed participants how students use inquiry skills to build a mental model of the box, just as scientists investigate and model often-invisible systems. In the "Mystery of the Iceman," participants examined a case study that helps students learn to distinguish between evidence and inference (BSCS, 2006). Finally, video clips of a high school optics lesson showed how particular science concepts can be taught using inquiry approaches (WGBH, 2000). Video segments showed the role of inquiry as a way to 'learn science,' while use of an example outside most participants' discipline focused attention on the teaching and learning strategies chosen rather than a particular curriculum.

Study Design - The study design used both quantitative and qualitative methods and drew upon three data sources: online pre-workshop surveys of all registrants, paper-based post-workshop surveys of all actual participants, and follow-up telephone interviews with a smaller sample. Survey data were used primarily to address formative and summative evaluation questions specific to ReSciPE's goals and approach, and space limitations preclude discussion of these findings. This paper focuses on the interview data to address research questions of general interest:

- What support and resources do research scientists need to become more effectively engaged in K-12 education?
- What are the implications of these needs for designing professional development activities to support education-engaged scientists?

STUDY METHODS

Interview Protocol - Thirty participants were selected from workshop registrants for extended, in-depth follow-up interviews conducted three to twelve months after their workshop participation. Most occurred within three to six months after workshop attendance, allowing time for participants to explore workshop ideas and activities in their own E/O practices and enabling us to assess the influence of the workshop on their subsequent thinking. Interview questions probed participants' beliefs and knowledge about inquiry and its effectiveness, the influence of the workshop on these, and broader professional development needs of scientists. Telephone interviews of 20-55 minutes were transcribed verbatim and entered into NVivo (2006) qualitative analysis software for coding and analysis. All research procedures complied with federal human subjects guidelines.

Qualitative Analysis Methods - The transcribed interviews were analyzed using domain analysis procedures developed by Spradley (1980). Units of meaning were identified and all interviews were coded for examples of these concepts or "cover terms" such as beliefs about inquiry, benefits of inquiry, or obstacles to participation in outreach. All text segments-responses to questions, spontaneous comments, narratives, and illustrations-referencing issues of different types were coded with these cover terms in Nvivo. When speakers made several points in the same passage, each idea was separately coded. Taxonomies were then constructed to link theoretical concepts and cover terms to coded examples through semantic relationships such as "is a kind of" or "is a way of doing." When possible, codes were also analyzed for variation with demographic and other variables, but the variability within the interview sample precluded meaningful analysis of many group differences.

The clustered codes and domains and their relationships define the themes of the qualitative analysis. In this report, we report the frequencies of clusters of codes to highlight the relative weighting of issues raised by participants. We used conservative counting methods to avoid overstating the weight of opinion; codes are only counted once per interview even if the topic was raised several times. We also report the number of individuals who raised a certain topic or made a specific observation. A low frequency does not necessarily reduce the importance of a statement-an explanation given by one individual may be insightful in explaining observations made by others. Thus, frequencies cannot be used to make statistical inferences, but are still useful to indicate general trends.

Characteristics of Interview Participants - The purposive sample of 30 interview participants generally mirrored the total workshop population. Consistent with other reports of greater interest in E/O by women scientists (Andrews et al., 2005; Tanner, 2000; Thiry, Laursen and Liston, 2007), 60% of all workshop participants were women. In the interview sample, women comprised 47%. For comparison, only 20% of American AGU members (Kirkbride, 2007), and 25% of recent doctorates in the physical sciences are women (NSF, 2004). Members of underrepresented groups, including African-Americans, Hispanics, and Native Americans, comprised 12% of the interview sample and 9% of all workshop participants. While less diverse than the U.S. population as a whole, this compares well with statistics on the science workforce: for example, fewer than 1% of Ph.D.s in the physical sciences are awarded to African-Americans, Hispanics, and Native Americans (NSF, 2004).

Because the workshops targeted research scientists, we purposefully selected a high proportion of research scientists to interview: 50% of interviewees listed their primary work activity as research, compared with only 31% of the total workshop population. Teachers comprised 23% of the interview sample, and administrators and outreach professionals were 26%. Eighty percent of interviewees held professional or career positions and 20% were graduate students. Finally, the proportion of research scientists is reflected in interviewees' institutional affiliations: 33% worked in government labs and 20% in doctoral institutions.

Interview participants were also highly involved in outreach activities. Eighty percent of the interview sample was actively involved in outreach, including 66% of research scientists. Thus, the research scientists in our study were likely to be involved in outreach, though to a lesser extent than administrators or other groups. Most research scientists spent one day a month or less on their outreach activities. Only half of the interview sample reported that outreach was a part of their formal job responsibilities.

RESEARCH FINDINGS

Overall, professional development was a large influence on participants' ideas about effective teaching and inquiry-based education. Respondents, particularly research scientists, recognized their need for more regular professional development and educational training. Statements about these needs are organized as the elements of a framework to guide professional development for education-engaged scientists.

The 30 interviewees made 114 distinct comments, or observations, about scientists' professional development needs. These observations fall into six major categories:

- motivation to engage in education and outreach and in professional development for this work (6 observations, 5% of all observations)
- access to professional development opportunities (15 observations, 13%)
- knowledge and skills (33 observations, 29%)
- applicability to their own E/O work (20 observations, 18%)
- broadened participation in E/O professional development (16 observations, 14%)
- post-workshop support for E/O activities (24 observations, 21%).

The first two categories characterize the support that research scientists need before they are ready to participate in professional development. The next three categories reveal elements of professional development offerings that are most helpful for research scientists. The final category elucidates the support scientists need after a professional development experience in order to apply new learning to their own work and to maintain a commitment to E/O work. Thus together these categories outline three sequential phases of scientists' participation in professional development, each bringing its own set of needs.

Drawing Scientists in: Support Needed to Engage Scientists in Professional Development - About one fifth of needs observations addressed drawing scientists into professional development to enhance their E/O work. This included motivating their participation and providing opportunities consistent with scientists' professional cultures.

Motivation - Motivation needs comprised 5% of total observations on scientists' professional development needs, raised by 17% of interviewees. Though this proportion was lower than other topics, providing education-related professional development is fruitless unless scientists are first motivated to attend. Lack of motivation to engage in E/O was ascribed more to the reward structure under which scientists operate than to lack of interest.

Reward structures were cited as a major barrier to motivation for both government and academic scientists. While scientists are now expected to engage in outreach to the public, they are not rewarded for doing so, as a graduate student noted:

> I'd say the biggest problem is one of motivation. And talking about scientists-particularly professors-the motivation to go to workshops, learn something about inquiry, try to use inquiry in their classrooms, is extremely low…. For one thing, pedagogical skills are not particularly rewarded in a university setting. Most of these people have little to no exposure to anything pedagogical whatsoever.

This quotation highlights two motivational barriers: an organizational structure that rewards research over teaching and service, and a lack of training in education. With little formal training in education, scientists may not recognize the benefits of high-quality professional development experiences, as an E/O specialist stated:

> You just gotta drag 'em [research scientists] in there…. I would just believe it's more awareness. I think once they know what's involved, I don't think they would have a problem doing it. But it's just getting them involved, and you just gotta kind of immerse them in it. And then once you do, I think they can think up all kinds of ways they could use it. …It's called, "You can lead a horse to water, but you can't make them drink." But if you get them to the water, and they look at it, I think they'll buy in.

Accessibility of Training - A primary concern of research scientists was the availability and accessibility of professional development in educational methods. Overall, 13% of needs observations, made by 33% of interviewees, addressed access to training. Many had received little or no training in pedagogy and wanted opportunities to learn about teaching and K-12 education. This finding is buttressed by national survey data: 23% of doctoral scientists and engineers listed teaching as one of the top two areas in which they would have liked more graduate training (NSF, 2001b).

Graduate school is one obvious locus for professional preparation for E/O work. The lack of preparation for teaching in graduate education in the sciences is well documented (Austin, 2002; Golde and Dore, 2001; NSF, 2001b; Smith, Pedersen-Gallegos, and Riegle-Crumb, 2002). Though 32% of Ph.D. scientists and engineers cite teaching as their primary or secondary work activity (NSF, 2001b), most receive little or no pedagogical training during their graduate programs. Teaching and outreach are devalued in some academic science departments, as research is more rewarded and holds higher status (Ferreira, 2003; Park, 1996; Thiry, Laursen and Liston, 2007). Yet teaching and communication skills are an increasing requirement even in research careers.

Research scientists in this study felt unprepared for their current involvement in education, and E/O specialists who worked with scientists likewise noted this lack of preparation. Better preparation during graduate school could provide the knowledge, skills, and confidence needed to communicate to lay audiences, as this E/O specialist commented:

> I think some early exposure to and training [in education] will really open eyes, and introduce some concepts and some approaches that graduate students in the ocean sciences and in the earth sciences don't often get in their graduate careers. I think that could be a big help.

Some suggested incorporating training in education into the standard curriculum for science graduate students. In recent years many programs have arisen to address this gap, but often they are optional "add-ons" (Thiry, Laursen, and Liston, 2007). To seek out and fit such programs into already-busy schedules requires initiative and interest, and students may not realize until later that they will need these skills. A research scientist commented:

> In graduate school you don't really get-unless you're in graduate school for education, you don't get any kind of training in this, in how to communicate your science and how to educate anybody from K-12 up to graduate students. And I think a lot of people could use a lot of help, but they also have to show an interest in wanting to learn some of the techniques.

Our interviewees wanted more educational training in graduate school, even when their job descriptions did not include teaching. A research scientist suggested:

> This is next to impossible to do, but it needs to become part of the curriculum for Masters and Ph.D. students. I would think it would help tremendously if such a class was required in all colleges and universities-and [if] industry/ government looked a little bit more favorably on people that had that sort of experience.

Beyond graduate school, scientists needed further opportunities to learn about education, which both scientists and E/O specialists agreed were rare. The initial lack of training thus continues into their professional careers, as this government scientist noted: "Make it available. We get very little of it. Official meetings, generally they don't want to fly us in a day or two before the meeting, and we have to go to all these presentations. It just has to be more available." Some suggested offering professional development in a variety of venues, such as conferences that already offer educational programming. Convenience, timing, and administrative support also influence whether researchers can pursue training.

Content Needs: Knowledge and Skills - Once scientists choose to pursue professional development and find convenient opportunities to do so, their next set of needs surrounds the content, effectiveness, and appropriateness of the professional development experience itself. Indeed, the needs most often discussed were the knowledge and skills that participants thought should be provided (29% of needs observations, offered by 47% of interview participants).

Focus on effective presentation and teaching methods - Recognizing their lack of formal training, research scientists called for professional development programs to focus on effective presentation techniques and teaching skills. They felt they could benefit from practical pointers on designing an effective presentation.

> Perhaps putting together workshops, and putting together presentations that would, for instance, incorporate the ideas about [effective presentation skills], how you can easily overwhelm things, or don't put too many fancy graphics, these sort of things-information that can be used to convey to folks who build presentations, how to make an effective presentation.

Participants agreed that effective presentation skills were necessary for all scientists, not just those involved with outreach, but critical to the dissemination and general reception of scientific work.

> For scientists who are not really into the education thing, I think [presentation skills are] still important, because a lot of scientists communicate with the public. And it's very important that they recognize that the public doesn't have the same background that they do. And it's very important that they understand that the way they communicate their science is critical to its acceptance.

Build a knowledge base of best practices in education - Interviewees, especially E/O specialists, also felt that scientists need to know "what works" in education. A professional developer discussed this need in the context of attending the ReSciPE workshop:

> It's always a benefit to me to learn about resources for scientists to use, and also to understand better what good teaching is all about… One of my roles is to help scientists invest a very limited amount of time that they have for education and public outreach wisely. And so that means trying to steer them towards collaborations that are likely to be really effective. And so if I can recognize what constitutes good education and outreach, I can make a better assessment of whether a particular opportunity or partnership might be a productive one for a scientist.

Another E/O professional emphasized the need for basic educational resources:

> A guide, a primer, a, document, guidance for [scientists] on different aspects… It may be new for many of them, and I think having resources like that, that are not overwhelming and not necessarily going into a lot of the theoretical and experiential grounding for how and why we know these things, but just kind of giving some basic advice.

Participants stressed that workshops and materials for scientists must be geared to a novice level. They do not need deep knowledge of cognitive psychology or learning theories, but they do need to know how people learn and what approaches best foster learning.

Understand research-based practices - Both research scientists and E/O professionals believed that one way to reach scientists is to appeal to the scientific method and present them with research-based findings about successful educational practices. In this way, scientists could become convinced of the value of effective approaches through the appeal to rigorous research that demonstrates their efficacy. For example, an academic scientist reflected on how educational research could inform outreach:

> If there were researchers who were able to devote some time to going into the classroom, seeing what works, seeing what doesn't, coming up with new things that work, but curriculum-specific-and even then, every state has different curriculum standards.

Professional developers thus need to educate scientists about educational research and to identify how research-based practices can also meet state curriculum standards.

Research data could also be effective, participants felt, in convincing scientists that traditional science education fails many students. Empirical evidence comparing learning and attitudes in traditional and reformed courses could help to persuade scientists that there are better ways to learn and teach. A student described seminars that he had attended:

> The ones that I liked the most were by people that were actually scientists that had then moved more into education. And so their approach to education was very scientific. This one guy was showing us data about students' attitudes toward science before taking a science class and after taking a science class. And, it seemed that after taking a science class, they were much less enthusiastic about science and thought it was much more about memorizing things rather than understanding concepts. And so his talk made an impression on me that, wow, in science classes this data is showing that we're doing everything wrong! …And that if this is the case, then we need to really change how we try to do things to actually have them have the attitudes afterwards that we want them to.

Particularly for research scientists, experiences in the ReSciPE workshops reinforced this point, helping to demonstrate the efficacy of inquiry methods. Workshop presenters provided an overview of relevant education research and participants engaged in several inquiry activities themselves. One scientist commented:

> [The workshop] sold me. Before, I had just read a couple of things, said, "That's pretty interesting."

> When I actually did it by using the little blocks, with little balls inside, and then saw the film about how these kids… these kids start asking questions, and figuring out the focal length, and the formulas that were involved, it was like, "Dang, look at that, these kids are actually doing this by themselves." They're learning to analyze the data that they have in their hands, and come up with an explanation for focal length… and that was pretty eye-opening.

This reinforcement of research evidence and personal experience mirrors observations by Hinkey, Ellenberg and Kessler (2005), who found that showing scientists how extension work resembled scientific work helped to engage scientists and increased their comfort with it. Likewise, ReSciPE participants, particularly research scientists, responded to a view of education research that compared inquiry learning-discovery of knowledge new to the student-with scientific discovery of knowledge new to all.

Needs for Relevance: Applicability to One's Own Work - In addition to the knowledge and skills required to effectively participate in E/O work, scientists need to see how to apply professional development experiences to their own work. Workshops, courses, coaching, publications, and other resources should relate ideas to scientists' own E/O activities. Transferability is particularly critical because most scientists lack formal educational training: they may not be able to use learning from a workshop if they do not understand how to translate it to their own outreach work.

Focusing on practical application of knowledge and skills is essential to help scientists identify ways to incorporate such practices into their own outreach lessons-a point stressed by scientists and graduate students, in particular. A research scientist said:

> Something that would be really, really useful, is just more ideas of how people have turned activities into inquiry, and how you can do inquiry in smaller steps. So I guess more of the nuts and bolts of it-how we can translate all these skills that we're getting from the workshop into the classroom.

Another way to aid transfer of workshop material is to give participants direct experience with real-life examples. Multiple examples of student activities help scientists take the concept of inquiry from abstract to concrete, as this graduate student noted.

> More hands-on activities… 'cause I think most of the people coming into [workshops] probably know a little, or have been exposed to what inquiry-based teaching is, but they may not have tried it much. And I think one of the benefits of a captive audience is to say, "Here, you have to do this lesson," right? "Here, go through this lesson, and do a couple different lesson plans," and just get them going through it. 'Cause I think the process of going through [inquiry-based activities], and asking questions, you can really think about how you can do similar projects and ask similar questions, on a completely different topic that you might be working on in the classroom.

Research scientists cited direct experience as contributing to their learning:

> I think the important thing about inquiry is that you have to have examples of it, and how it works, and how it can work. And so I think, certainly the exercises that we did, and kind of experiencing inquiry, is always really helpful to understand better what it is, and how it can be implemented.

Realistic involvement with outreach given constraints - Another way to help education-related professional development apply to participants' own work is to help them recognize and overcome barriers. Scientists need to identify appropriate ways to contribute within their own constraints. Workshop participants reported several factors that negatively affected their outreach participation, such as lack of time, lack of support, and lack of knowledge about how to effectively engage in E/O activities. In acknowledging these constraints, interviewees advised that professional development experiences should help them to identify sustainable ways to become involved in E/O. A graduate student suggested, "Give [scientists] structure, or introduce ways that they can be involved so it's not burdensome."

Lack of knowledge about opportunities and whether these are effective investments of time can also impede broader participation in outreach. A research scientist called for more assistance in identifying ways to become involved with students and education.

> Providing ways, and maybe tips and guidance for how they [scientists] can be useful… [for example,] guide, be some sort of advisor for a kid. And being given a heads-up of what ten-year-olds need, where they are in terms of their educational level. So that's the big thing-if people don't know about something, it can seem very overwhelming and too much of a task.

Professional development experiences for research scientists must use approaches that help scientists effectively transfer their learning to their own E/O activities, and must also guide scientists toward outreach activities that are realistic given their individual constraints.

Broadened Participation in Training and Outreach - Interviewees also addressed how the audience for professional development could help to create meaningful learning experiences for scientists. These observations constituted 14% of needs observations, raised by 57% of interviewees.

Collaboration between scientists and educators - Participants felt that professional development workshops were most effective when both scientists and educators were in attendance. Both groups recognized parallels in their work and urged more collaboration. Understanding how classroom inquiry parallels scientific knowledge discovery highlighted the contributions that both groups could make to science education. Thus scientists could benefit from learning how educators design lessons and teach, and educators could benefit from reflection on inquiry as an approach to teaching the scientific process and nature of science. A research scientist commented:

> I think a lot of times they really sort of need to get together to understand-[even] when they have a mutual respect for each other, they don't always really understand each other's needs and thought processes. So actually getting them together on some projects would be useful…. It's just like in inquiry-trying to do science the way scientists do it-and scientists may need to do education the way educators do it, to appreciate the needs that go into curriculum design.

Participants believed that educational outreach programs are most successful when scientists and educators work together from the start. Educators can help scientists be effective presenters, interact in ways that are developmentally appropriate for children, and understand how to work in schools. An E/O professional said:

> Scientists have a requirement to put so much money into education as a part of their funding. And so they are struggling-they want to do something valuable, and that will be helpful to the educational process. And I think the situations that I saw where people… engaged educators right away at the ground level, had the most successful programs, and most likely to be re-funded. So I would say that that connection of educators and scientists, is very, very important.

Researchers likewise acknowledged that educators could provide valuable feedback:

> More interaction between the teachers and the scientists. I've found it extremely important, over the years, to take time after the presentation, and sit down with the teachers and say, "How did I do, what can I do better, and what do you expect?" so that each time I am able to more closely tailor my presentation to their desires.

Greater participation in professional development activities - Interviewees felt that regular professional development experiences could have a powerful impact on scientists' views of learning and teaching. But scientists do not partake of training often, even that related to their primary job responsibilities. For example, just 53% of doctoral scientists and engineers participated in work-related training in the prior year (NSF, 2001b). We can assume the fraction receiving training for secondary tasks, such as outreach, was far lower. Yet 100% of the research scientists interviewed mentioned a professional development experience (ReSciPE or other) as highly influential to developing their beliefs about inquiry and education. Though barriers of motivation and accessibility were noted, they agreed that scientists need to become more active in education and receive appropriate professional development for such work. An outreach specialist commented, "While I don't get to attend a lot of professional development workshops, I very enthusiastically encourage scientists who have an interest in participating in [outreach] to do those things." And all of the research scientists interviewed would recommend the ReSciPE workshop to colleagues: "For me personally, I thought it was very helpful. So I would encourage my colleagues to participate and to think about [inquiry] as a teaching approach."

Support for Continued Involvement with Educational Outreach - We have discussed scientists' need for initial support to engage with education and outreach, and their need for meaningful professional development experiences to build knowledge, skills, and collaborations. However, scientists also need follow-up support to maintain their commitment to improving science education. Observations on ongoing support represent 21% of all needs statements, made by 33% of interviewees.

A common topic, mentioned by research scientists more than by others, was the need for administrative support. Because outreach is a small part of their job, researchers in both academe and government need visible support to commit time and resources to outreach. For example, attendees at one site commented positively when a high-level administrator attended the ReSciPE workshop at their laboratory. As one scientist noted:

> It really helps when it's supported in your agency or lab, to know that, "Hey, this is something important, and that we consider this something that is important enough that you can maybe go do it in the afternoon on a workday," or something like that. And the support in that sense, I think, is really useful.

In addition to public valuing of E/O work, scientists needed concrete support for the work itself. For example, one scientist suggested how a mentor could help improve E/O activities and build on ideas gained from professional development experiences.

> I think it's having somebody who does that kind of thing as, say, a mentor, or [who] are available, that they could show me how others have done it and then I can incorporate it into what I'm doing. 'Cause I'm kind of alone in this thing, and I'm trying to figure out, "What could I do?" that would make it better.

E/O professionals noted that research scientists generally work in isolation from educators, and have no professional network of colleagues to whom to turn for advice and support:

> I think that they [scientists] need to know who they can contact in a department of education to work with on a more continual basis. They had the workshop, but they're still going to be working in almost a vacuum. And the schools themselves don't necessarily have somebody-if they do have somebody, they don't know who they are. But I think it would help to have a contact that they can continue to partner with past the workshop. I think that would really help them.

Finally, research scientists noted a need to build relationships with others with similar interests and goals. They did not often discuss outreach, even with colleagues who also engaged in outreach, as this exchange illustrates.

> Interviewer: And do you ever discuss ideas with [colleagues], or discuss education with them?
>
> Research scientist: No.
>
> Interviewer: Do you have a lot of interaction with them?
>
> Research scientist: Our outreach is pretty much confined to somebody saying, "Oh, I'm leaving for outreach today, I'll see ya, goodbye." (laughs) And that's basically the extent of our discussion about it.

Another research scientist reported that her outreach activities were curtailed because she could not find a colleague to join an outreach funding opportunity: "Recently… there was some funding to do education stuff, so I looked around for people who could help me do something. But I wasn't successful in finding anybody! So I didn't propose anything."

A faculty member recognized the need to work in a community and valued the ReSciPE workshop for helping him re-connect with colleagues in science education.

> [I benefited from] re-connecting to the community of educators and realizing that I wasn't going to be alone. I've been out of it-I've been out of academia, and I came back into it sort of needing to catch up, and, and find out where things stood. …It got me back up to speed, and really made me feel like this was possible-that there were resources, and people committed to this, and it was just invigorating.

Indeed, a common benefit was participants' realization that they were not alone. Many had felt that their interest in E/O was uncommon within their own institutions, and were thus gratified to discover others with similar interests.

> I was surprised-well, not completely surprised, but a little bit encouraged to see how many people actually showed up to that workshop. So that was good news to see that there are quite a few people working out there, and doing outreach stuff and all that.

To summarize, education-engaged scientists expressed needs for post-workshop support of their E/O activities: mentors and colleagues to collaborate and help them apply new knowledge and skills, and visible support from their institutions.

DISCUSSION

Our findings show that education-engaged scientists recognize a need for professional development for their education work; will participate in an education-focused workshop; and realize benefits from attending. These findings are encouraging for policy makers and advocates who urge scientists' involvement in science education. We now consider the practical implications for program developers and agencies who seek to draw scientists into science education and to support them to do effective work.

First, we have organized our analysis of scientists' E/O professional development needs in a three-stage framework that addresses how to draw scientists in, what and how to provide, and what they need afterwards. The framework is broad, covering needs for knowledge, skills, and collegial interactions, and pragmatic concerns. However, it does not necessarily address all areas of need-in particular, beliefs. Beliefs are important influences on the educational practices of college faculty, for instance (Trigwell and Prosser, 1996a, 1996b; Kane, Sandretto and Heath, 2002; Ho, Watkins and Kelly, 2001). Some education-engaged scientists have described their own experiences of how beliefs about education can misdirect efforts and limit effectiveness (Bower, 1996; Morrow, 2003). As people who succeeded in the present educational system, scientists may not recognize the varied needs of other learners. Alberts points out, "We all think we understand education because we did well ourselves. It worked for us, and we think it should work for everybody else. But that's a big mistake" (Mervis, 2005, p. 1108).

Evidence from this study also points to the importance of beliefs. In particular, changes in beliefs did occur as a result of the workshop, though they were not identified as a "need." Indeed, all of the research scientists in the interview study cited professional development as highly influential in transforming their beliefs about teaching and learning, and survey results (not described) also support this contention. Moreover, the ReSciPE workshops deliberately targeted scientists' beliefs, presenting research evidence to help persuade them that these methods were effective, and providing hands-on experiences to give personal insight. Lively discussions were typical as scientists challenged these ideas and argued with each other. While scientists in our sample did not directly identify belief change as a need, this issue is recognized by those who work with them and by scientists themselves as they gain experience. Attention to beliefs should thus be included when using this framework to design a professional development experience.

Our findings concur with those of Andrews et al. (2005) on the importance of intrinsic factors-interest and enjoyment-in scientists' recruitment to and rewards from E/O work. To this we add pragmatic considerations such as broader impacts obligations. Our findings also reiterate the importance of institutional structures-such as coordinated information about E/O opportunities and appropriate preparation-in sustaining scientists' E/O contributions. Andrews et al. (2005) describe their study participants as "early adopters" of outreach, and a difference in tone is evident between comments quoted there and those quoted here. Our respondents seem more cognizant of scientists' responsibility as a group to contribute to science education, rather than seeing outreach as an optional volunteer activity. Perhaps that difference reflects a shift in the discourse in the scientific community since Andrews et al. gathered data in 1999-2000.

Our findings also compare well with survey results (Storksdieck et al., 2002) on another group of education-engaged scientists, amateur astronomers. Amateurs are stalwart volunteers in classroom astronomy programs and perceived by teachers as equally effective to professionals in engaging students and addressing student misconceptions (Gibbs and Berendsen, 2007). Storksdieck et al.'s (2002) respondents wanted more resources for preparing presentations;

communication and presentation skills; networking; and understanding of the particular needs of different audiences. However, professional developers will need to account for these differences-for example, motivation may be less of an issue, but access to professional development a more significant one.

The literature on professional development in science education for teachers (Loucks-Horsley et al., 2003; Banilower et al., 2006; Garet et al., 2001) and college faculty (Burke, Greenbowe, and Gelder, 2004; Lewis and Lewis, 2006; Penberthy and Connolly, 2000; Marder et al., 2001; Sell, 1998) generally echoes points made here, such as the importance of engaging learning experiences, relevance to participants' own practice, and follow-up. However, lessons from professional development for these groups cannot be directly applied to scientists. Education is a primary task of teachers and faculty, but it is by definition a lesser responsibility for working scientists, and will remain so for most. Thus a key issue is the values system within which scientists operate. Whether in policy (Mathews, Kalfoglou and Hudson, 2005; Nicholas 1999, 2001) or education (Brown et al., 2004; Andrews et al., 2005; Storksdieck et al., 2002), scientists cite "lack of time" as the main barrier to public engagement. Yet choices on how to spend time, ultimately, reflect priorities: people spend time on what they perceive to matter. Thus statements about time really reflect a lack of value on outreach within the reward system of science (Andrews et al., 2005; Mathews, Kalfoglou and Hudson, 2005; Brown et al., 2004). Changes to the reward structure are needed, not only to destigmatize outreach-removing the fear of "Sagan syndrome" (Mathews, Kalfoglou and Hudson, 2005)-but to actively reward it.

Moreover, rewarding outreach means measuring its quality and impact, as Huber (1999) points out. This implies both evaluating the outcomes of E/O efforts-student learning, attitudes, persistence, teacher effectiveness, or other goals-and scientists' influence on these outcomes. Universities are examining how to evaluate and reward the "scholarship of engagement" (Boyer, 1996; Glassick, Huber and Maeroff, 1997; Checkoway, 2001), and some practical examples of efforts to evaluate E/O have been offered (Pelaez and Gonzalez, 2002; Bartel, Krasny and Harrison, 2003; Driscoll and Lynton, 1999). Other strategies will be needed for different structures and cultures in companies, labs, and institutes where scientists also work (NRC 1996).

Finally, we acknowledge some limitations of our study. Most importantly, the sample is comprised of education-engaged scientists, most of whom were already actively involved in outreach and who attended the ReSciPE workshop voluntarily, seeking a professional development opportunity in education. This population undoubtedly does not represent the overall population of U.S. geoscientists. Further research is needed on scientists who are not actively engaged in E/O to determine their interest, motivation, and barriers to participation. Only with this information is it possible to assess the likely fruitfulness of efforts to engage them, or to judge whether effort is better spent on improving the effectiveness of those who are already engaged.

CONCLUSION

Science education and outreach are currently receiving greater attention and interest from working scientists than ever before. Yet, in the pithy words of Brown et al. (2004), "The culture of science today does not encourage or endorse participation by scientists in activities of public outreach… nor does educational preparation for a professional career in the sciences include orientation or training to the public context of science" (p. 295).

Findings from the ReSciPE Project address both these issues. The ReSciPE workshops were conducted as an experiment to enhance scientists' preparation for their E/O work. The high participation and diversity of the workshop audience, and evaluation data on changes in scientists' knowledge, beliefs, and practices, offer evidence that this model has succeeded in attracting scientists and providing useful, relevant knowledge. But a nationally traveling workshop model has other limitations in its short duration and lack of follow-up. Elsewhere we have analyzed this workshop as an example of how to use the research framework to identify tradeoffs and design appropriate professional development (Laursen, Thiry and Hunter, 2008). Our research findings offer a general framework that can help to guide development of an array of local and national professional development models to meet scientists' needs. Scientists and educators can use this framework in planning and developing appropriate professional development activities to support their own local and regional E/O projects; scientific organizations can support and advertise professional development opportunities; and funders can encourage experimentation with careful evaluation to determine what is effective.

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REFERENCES

Alberts, B. M., 1991, Elementary science education in the United States: How scientists can help, Current Biology, v. 1, p. 339-341.

Andrews, E., Hanley, D., Hovermill, J., Weaver, A., and Melton, G., 2005, Scientists and public outreach: Participation, motivations, and impediments, Journal of Geoscience Education, v. 53, p. 281-293.

Austin, A.E., 2002, Preparing the next generation of faculty: Graduate school as socialization to the academic career. Journal of Higher Education, v. 73, p. 94-122.

Banilower, E. R., Boyd, S. E., Pasley, J. D., and Weiss, I. R., 2006, Lessons from a Decade of Mathematics and Science Reform:A Capstone Report for the Local Systemic Change through Teacher Enhancement Initiative, Report to the National Science Foundation, Horizon Research, Chapel Hill, NC.

Bartel, A. S., Krasny, M., and Harrison, E. Z., 2003, Beyond the binary: Approaches to integrating university outreach with research and teaching,

Journal of Higher Education Outreach and Engagement, v. 8, p. 89-104.
Beck, M. R., Morgan, E. A., Strand, S. S., and Woolsey, T. A., 2006, Volunteers bring passion to science outreach, Science, v. 314, p. 1246-1247.
Biological Sciences Curriculum Studies (BSCS), 2006, Mystery of the Iceman, In: BSCS Science: An Inquiry Approach Level 1 (student ed.), Dubuque, IA, Kendall/Hunt.
Bower, J. M., 1996, Science education reform: How can we help? Issues in Science and Technology, v. 12, p. 55-60.
Boyer, E., 1996, The scholarship of engagement, Journal of Public Outreach, v. 1, p. 11-20.
Bransford, J. D., Brown, A. L., and Cocking, R. R., eds., 1999, How People Learn: Brain, Mind, Experience, and School, National Research Council, National Academies Press, Washington, DC.
Brown, C. P., Propst, S. M., and Woolley, M., 2004, Report: Helping researchers make the case for science, Science Communication, v. 25, p. 294-303. DOI:10.1177/1075547003262599.
Bruce, B. C., Bruce, S. P., Conrad, R. L., and Huang, H.-J., 1997, University science students as curriculum planners, teachers, and role models in elementary school classrooms, Journal of Research on Science Teaching, v. 34, p. 69-88.
Burke, K., Greenbowe, T., and Gelder, J., 2004, The Multi-Initiative Dissemination Project workshops: Who attends them and how effective are they? Journal of Chemical Education, v. 81, p. 897-902.
Busch, A., and Tanner, K. D., 2006, Developing scientist educators: Analysis of integrating K 12 pedagogy and partnership experiences into graduate science training, National Association for Research in Science Teaching, San Francisco, CA, April 2006.
Bybee, R., 1998, Improving precollege science education, the role of scientists and engineers, Journal of College Science Teaching, v. 27, p. 324-328.
Bybee, R. W., and Morrow, C. A., 1998, Improving science education: The role of scientists, Fall 1998 newsletter of the Forum on Education of the American Physical Society, http://www.spacescience.org/education/education_papers.html (9 June, 2007).
Checkoway, B., 2001, Renewing the civic mission of the American research university. Journal of Higher Education, v. 72(2), p. 125-147.
Community Resources for Science (CRS), no date, Berkeley, CA, http://www.crscience.org/scientists/training.html (9 June, 2007).
Colwell, R. R., and Kelly, E. M., 1999, Science learning, science opportunity, Science, v. 286, p. 237.
Dolan, E. L., Soots, B. E., Lemaux, P. G., Rhee, S. Y., and Reiser, L., 2004, Strategies for avoiding reinventing the precollege education and outreach wheel, Genetics, v. 166, p. 1601-1609.
Driscoll, A., and Lynton, E. A., 1999, Making Outreach Visible: A Guide to Documenting Professional Service and Outreach, AAHE Forum on Faculty Roles and Rewards, Washington, DC, American Association for Higher Education.
Evans, C. A., Abrams, E. D., Rock, B. N., and Spencer, S. L., 2001, Student/scientist partnerships: A teachers' guide to evaluating the critical components, American Biology Teacher, v. 63, p. 318-323.
Falk, J., and Drayton, B., 1997, Dynamics of the relationships between science teachers and scientists in an innovative mentorship collaboration, Annual Meeting of the American Educational Research Association, Chicago, IL, March, 1997, ERIC Document Reproduction Service No. #ED412085.
Feldstein, S. M., and Benner, M. S., 2004, Assessing outcomes of a secondary-postsecondary partnership model for biology education outreach, American Biology Teacher, v. 66, p. 114-119.
Ferreira, M., 2003, Gender issues related to graduate student attrition in two science departments, International Journal of Science Education, v. 25, p. 969-989.
FOSS (Full Option Science System), no date, Models and Designs, http://lhsfoss.org/scope/folio/html/ModelsAndDesigns/1.html (9 June, 2007).
Fraknoi, A., 2005, Steps and missteps toward an emerging profession, Mercury, v. (September-October), p. 19-25.
Franks, S., McDonnell, J., Peach, C., Simms, E., and Thorrold, A., 2006, EPO Education and Public Outreach; A Guide for Scientists, Rockville, MD, The Oceanography Society http://www.tos.org/epo_guide (12 June, 2007).
Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., and Yoon, K. S., 2001, What makes professional development effective? Results from a national sample of teachers, American Education Research Journal, v. 38, p. 915-945.
Gibbs, M. G., and Berendsen, M., 2007, Effectiveness of amateur astronomers as informal science educators, Astronomy Education Review, v. 5, p. 114-126.
Gilmer, P. J. Granger, D. E., Butler, W. (eds.), 2005, Science Graduate Students in K-8 Classrooms:Experiences and Reflections, Tallahassee, FL, Southeast Eisenhower Regional Consortiumm for Mathematics and Science Education, Florida State University.
Glassick, C. E., Huber, M. T., and Maeroff, G. I., 2000, Scholarship Assessed: An Evaluation of the Professoriate, San Francisco, Jossey-Bass.
Golde, C. M. and Dore, T. M., 2001, At Cross Purposes: What the experiences of today's doctoral students reveal about doctoral education, A report prepared for the Pew Charitable Trusts. www.phd-survey.org (15 July, 2007).
Hinkey, L. M., Ellenberg, K. T., and Kessler, B., 2005, Strategies for engaging scientists in collaborative processes, Journal of Extension, v. 43(1), #1FEA3, http://www.joe.org/joe/2005february/a3.shtml (10 June, 2007).
Ho, A., Watkins, D., and Kelly, M., 2001, The conceptual change approach to improving teaching and learning: An evaluation of a Hong Kong staff development programme, Higher Education, v. 42, p. 143-169.
Huber, M. T., 1999, Evaluating outreach: Scholarship Assessed's approach, Ch. 9 in Best Practices in Outreach and Public Service: The "Scholarship of Engagement" for the 21st Century, College Station, PA, Outreach and Cooperative Extension, Pennsylvania State University, http://www.outreach.psu.edu/News/Pubs/Monograph/eval.html (9 June, 2007).
Kane, R., Sandretto, S., and Heath, C., 2002, Telling half the story: A critical review of research on the teaching beliefs and practices of university academics, Review of Educational Research, v. 72, p. 177-228.

Kirkbride, T., 2007, AGU membership data, personal communication (6/18/07).

Koehler, B. G., Park, L. Y., and Kaplan, L. J., 1999, Science for kids outreach programs: college students teaching science to elementary school students and their parents, Journal of Chemical Education, v. 76, p. 1505-1509.

Laursen, S. L., 2006, Getting unstuck: Strategies for escaping the science standards straitjacket, Astronomy Education Review, v. 5, p. 162-177, http://aer.noao.edu/cgi-bin/article.pl?id=206

Laursen, S. L., Thiry, H., and Hunter, A.-B. (2008). Professional development for education-engaged scientists: A research-based framework. In Garmany, C. D., and Gibbs, M. G. (eds.), EPO and a Changing World: Creating Linkages and Expanding Partnerships, ASP Conference Series. San Francisco: Astronomical Society of the Pacific, forthcoming.

Laursen, S. L., Thiry, H., and Liston, C., 2008, Filling a gap in graduate education: Professional preparation in teaching for STEM graduate students through participation in K-12 outreach, manuscript in review.

Laursen, S., Liston, C., Thiry, H., and Graf, J., 2007, What good is a scientist in the classroom? Participant outcomes and program design features for a short-duration science outreach intervention in K-12 classrooms, CBE-Life Sciences Online, v. 6, p. 49-64, DOI: 10.1187/cbe.06-05-0165, http://www.lifescied.org/cgi/content/full/6/1/49

Leshner, A. I., 2007, Outreach training needed, Science, v. 315, p. 161.

Lewis, S. E., and Lewis, J. E., 2006, Effectiveness of a workshop to encourage action: Evaluation from a post-workshop survey, Journal of Chemical Education, v. 83, p. 299-304.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., and Hewson, P. W., 2003, Designing Professional Development for Teachers of Science and Mathematics (2nd ed.), Thousand Oaks, CA, Corwin Press.

Marder, C., McCullough, J., Perakis, S., and Buccino, A., 2001, Evaluation of the National Science Foundation's Undergraduate Faculty Enhancement (UFE) Program. Report prepared for the National Science Foundation, Directorate of Education and Human Resources, Division of Research, Evaluation and Communication, by SRI International, Higher Education Policy and Evaluation Program, http://www.nsf.gov/pubs/2001/nsf01123/ (24 July, 2007).

Mathews, D. J. H., Kaloglou, A., and Hudson, K., 2005, American Journal of Medical Genetics, v. 137A, p. 161-169.

Mervis, J., 2005, Attention, class: A departing NAS president speaks his mind, Science, v. 308, p. 1108-1109. DOI: 10.1126/science.308.5725.1108

Messmore, A. B., 1996, Measuring the impact of grassroots outreach, Science Communication, v. 17, p. 430-442.

Mitchell, J., Levine, R., Gonzalez, R., Bitter, C., Webb, N., and White, P., 2003, Evaluation of the National Science Foundation Graduate Teaching Fellows in K-12 Education (GK-12) Program, Annual Meeting of the American Educational Research Association, Chicago, IL, April 21-25, 2003, ERIC Document Reproduction Service No. ED 478204.

Morrow, C. A. , 2000, The diversity of roles for scientists in K-14 education and public outreach, Unpublished white paper, http://www.spacescience.org/education/education_papers.html (9 June, 2007).

Morrow, C. A., 2003, Misconceptions scientists often have about the K-12 National Science Education Standards, Astronomy Education Review, v. 1, p. 85-94.

Morrow, C. A., and Dusenberry, P. B., 2004, Workshops for scientists and engineers on education and public outreach, Advances in Space Research, v. 34, p. 2153-2158.

Munn, M., Skinner, P. O., Conn, L., Horma, H. G., and Gregory, P., 1999, The involvement of genome researchers in high school science education, Genome Research, v. 9, p. 597-607.

NASA, 1996, Implementing the Office of Space Science Education/Public Outreach Strategy, http://spacescience.nasa.gov/admin/pubs/edu/imp_plan.htm (9 June, 2007).

National Research Council (NRC), 1996, The Role of Scientists in the Professional Development of Science Teachers, Committee on Biology Teacher Inservice Programs, Board on Biology, Commission on Life Sciences, http://www.nap.edu/readingroom/books/role/index.html (10 June, 2007).

National Science Foundation (NSF), 1997, Geoscience education: A recommended strategy, NSF 97-171, NSF Directorate for Geosciences, http://www.nsf.gov/pubs/1997/nsf97171/nsf97171.htm (9 June, 2007).

National Science Foundation (NSF), 2001a, Working group on implementation of review-Criterion #2. Office of Polar Programs Advisory Committee. http://www.nsf.gov/od/opp/opp_advisory/oaccrit2.jsp (9 June, 2007).

National Science Foundation (NSF), 2001b, Doctoral Scientists and Engineers: 2001 Profile Tables, Division of Science Resources Statistics, NSF 04-312, Arlington, VA.

National Science Foundation, 2002, "Dear Colleague" letter from Arthur B. Ellis, Division of Chemistry, NSF 02-161, http://www.nsf.gov/pubs/2002/nsf02161/nsf02161.htm
(9 June, 2007).

National Science Foundation (NSF), 2003, Merit Review Broader Impacts Criterion: Representative Activities, http://www.nsf.gov/pubs/2003/nsf032/bicexamples.pdf (9 June, 2007).

National Science Foundation (NSF), 2004, Women, Minorities, and Persons with Disabilities in Science and Engineering: 2004, Division of Science Resources Statistics, NSF 04-317, Arlington, VA.

Nicholas, B., 1999, Molecular geneticists and moral responsibility: "Maye if we were working on the atom bomb I would have a different argument," Science and Engineering Ethics, v. 5, p. 515-530.

Nicholas, B., 2001, Exploring a moral landscape: Genetic science and ethics, Hypatia, v. 16, p. 45-63.

NVivo 7, 2006, QSR International Pty. Ltd., Doncaster, Victoria, Australia.

Olson, S., and Loucks-Horsley, S., eds., 2000,Inquiry and the National Science Education Standards: A Guide for Teaching and Learning, National Research Council, Washington, DC, National Academies Press.

Park, S. M., 1996, Research, teaching, and service: Why shouldn't women's work count? Journal of Higher Education, v. 67, p. 46-84.

Pelaez, N. P., and Gonzalez, B. L., 2002, Sharing science: Characteristics of effective scientist-teacher interactions, Advances in Physiology Education, v. 26, p. 158-167.

Penberthy, D., and Connolly, M., 2000, Final report on evaluation of New Traditions workshops for chemistry faculty: Focus on follow-up surveys documenting outcomes for workshop participants, Report prepared for New Traditions Project by the LEAD Center, http://www.cae.wisc.edu/~lead/pages/internal.html (24 July, 2007).

ReSciPE, 2005, Online resources: The ReSciPE Book.Resources for Scientists in Partnership with Education, http://cires.colorado.edu/education/k12/ReSciPE/collection/ (15 June, 2007).

Richmond, G., 1996, University/school partnerships: Bridging the culture gap, Theory into Practice, v. 35(3, summer), p. 214-218.

Sell, G. R., 1998, A review of research-based literature pertinent to an evaluation of workshop programs and related professional development activities for undergraduate faculty in the sciences, mathematics and engineering, Report commissioned by SRI International as part of an evaluation for the Undergraduate Faculty Enhancement (UFE) program for the National Science Foundation.

SEP, 2007, Science and Health Education Partnership, University of California, San Francisco http://biochemistry.ucsf.edu/~sep/orientation.html (9 June, 2007).

Smith, S.; Pedersen-Gallegos, L.; Riegle-Crumb, C., 2002, The training, careers, and work of Ph.D. physical scientists: Not simply academic, American Journal of Physics, v. 70, p. 1081-1092.

Spradley, J.P., 1980, Participant Observation, New York, Holt, Rinehart, and Winston.

SPSS, 2006, version 15.0, SPSS Inc., Chicago, IL.

Stamp, N., and O'Brien, T., 2005, GK-12 partnership: A model to advance change in science education. BioScience, v. 55, p. 70-77.

Storksdieck, M., Dierking, L. D., Wadman, M., and Jones, M. C., 2002, Amateur Astronomers as Informal Science Ambassadors: Results of an Online Survey, Report to the Astronomical Society of the Pacific, Annapolis, MD, Institute for Learning Innovation.

Tanner, K. D., 2000, Evaluation of scientist-teacher partnerships: Benefits to scientist participants, National Association for Research in Science Teaching, New Orleans, LA, April 2000.

Tanner, K. D., Chatman, L., and Allen, D., 2003, Approaches to biology teaching and learning: Science teaching and learning across the school-university divide-Cultivating conversations through scientist-teacher partnerships, Cell Biology Education, v. 2, p. 195-201, DOI:10-1187/cbe.03-10-0044, http://www.lifescied.org/cgi/content/full/2/4/195 (9 June, 2007).

Thiry, H., Laursen, S. L., and Liston, C., 2007, (De)Valuing teaching in the academy: Why are underrepresented graduate students over-represented in teaching and outreach?, Journal of Women and Minorities in Science and Education, 13, 391-419.

Thompson, S. L., Collins, A., Metzgar, V., Joeston, M. D., and Shepherd, V., 2002, Exploring graduate-level scientists' participation in a sustained K-12 teaching collaboration. School Science and Mathematics, v. 102, p. 254-265.

Trautmann, N., Avery, L., Krasny, M., and Cunningham, C., 2002, University science students as facilitators of high school inquiry-based learning, In: Annual Meeting of the National Association for Research in Science Teaching. New Orleans, LA, April 7-10, 2002, http://ei.cornell.edu/pubs/CEIRP_NARST_02.pdf (16, August, 2006).

Trautmann, N., and Krasny, M., 2006, Integrating teaching and research: A new model for graduate education? BioScience, v. 56, p. 159-165.

Trigwell, K., and Prosser. M., 1996a, Congruence between intention and strategy in university science teachers' approaches to teaching, Higher Education, v. 32, p. 77-87.

Trigwell, K., and Prosser, M., 1996b, Changing approaches to teaching: A relational perspective, Studies in Higher Education, v. 21, p. 275-284.

WBGH, 2000, Teaching High School Science video series, Boston, http://www.learner.org/resources/resource.html?uid=126 (15 July, 2007).

Wier, E. A., 1993, Scientist and teacher partnerships in elementary schools, Annual Meeting of the National Association for Research in Science Teaching, Atlanta, GA, April 1993, ERIC Document Reproduction Service No. #ED360182.