

Scientists' Participation in Education and Outreach for the PBO Nucleus Project

A Report to UNAVCO

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Executive Summary

Scientists who had participated in education and outreach (E/O) efforts sponsored by UNAVCO Education and Outreach during the period 2005-2008 were surveyed as part of the evaluation plan for the PBO Nucleus project, a project affiliated with the Plate Boundary Observatory and EarthScope. The scientists were asked about their role in E/O, their motivation to participate, their awareness of UNAVCO outreach programs, the benefits to them of participating, and the barriers to participation. They were also asked their general views of the National Science Foundation's use of Review Criterion 2, "broader impacts," as a tool for encouraging scientists to participate and invest in science education. Of 34 scientists surveyed, 23 responded, or 68%.

The findings show that the scientists surveyed were generally active in education and outreach, both through their direct work on this project with the UNAVCO E&O staff, and outside it. though their responses showed a wide range of levels and types of E/O activities. Their most common activities for UNAVCO were playing an advisory or leadership role, providing scientific review of educational materials, and presenting to educators in dissemination workshops. The responding scientists were primarily motivated to participate by their belief that they had important ideas to communicate about fundamental concepts about Earth systems, the process of science, and the relevance of these to everyday life. They also were motivated by their enjoyment of outreach work and their sense that they were good at it.

Though this group of scientists was directly involved in the UNAVCO-sponsored E/O efforts on behalf of PBO Nucleus, they were not highly aware of these efforts overall. This may reflect their specific contact with one program element, and suggests opportunities to raise awareness more widely. Scientists viewed the PBO Nucleus outreach effort, and their own contributions to it, as moderately effective. They expressed optimism that it could improve further and saw potential for this in coordinating with the broader EarthScope E/O effort and in focusing efforts more tightly. Some recognized the limitations of their own knowledge about the program's effectiveness as well as limitations to their abilities to be effective in their E/O roles. These findings suggest opportunities for strengthening the program overall and enhancing scientists' contributions.

Because some of the respondents were college instructors, we asked about their use of the UNAVCO-developed educational materials that are available online. Fifteen of the respondents taught courses on topics relevant to these materials, but only five of these had used the materials. However, these five had made extensive use of the materials, and the other ten reported they intended to use them in the future. This suggests a substantial opportunity to raise both awareness and use of these materials among college instructors who already teach relevant

courses. This group has the existing expertise to make use of the educational materials with little hand-holding, and thus may be a fruitful target for dissemination.

The benefits and barriers reported by survey respondents are generally similar to those reported in the literature. Time and logistics were the greatest barriers reported, and the greatest benefits the intrinsic pleasure and reward from doing something seen as worthwhile. Scientists generally held positive views of the appropriateness and impact of “broader impacts”. However, these education-engaged scientists perceive themselves as outliers in their scientific communities; while they value E/O and feel confident about their own ability to do it well, they do not perceive that this level of value and effectiveness is equally high among their colleagues. The results suggest several ways in which professional development for education-engaged scientists might enhance their effectiveness in their E/O work.

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I. Context for the Study

Scientists' involvement in education and outreach (E/O) has been argued to be crucial in improving pre-college education (Alberts, 1991; Bybee, 1998; Colwell & Kelly, 1999; NRC, 1996). Some scientists become involved out of personal interest, altruistic desires, or beliefs that they have a duty to contribute to public science literacy and high-quality science education in schools (Falk & Drayton, 1997; Andrews et al., 2005). Others have been drawn into E/O activities through requirements of their funding agencies. In particular, about a decade ago, the National Science Foundation (NSF) announced changes in the evaluation of one of its two main review criteria (NSF, 1997, 2001, 2003). Since then, research proposals have been required to explicitly address the "broader impacts" of their research—on education, public understanding of science, diversity of the scientific workforce, or scientific infrastructure—as well as the intellectual merit of the proposed study. Following the change in NSF's practice, many scientific research projects—especially large collaboratives, which are not uncommon in the geosciences—have addressed broader impacts by incorporating explicit E/O activities. They have hired professional science educators to lead these activities and made deliberate efforts to involve scientists in them.

The Plate Boundary Observatory (PBO) is one such project. PBO is the geodetic component of EarthScope, established to study tectonic deformation in the western United States due to plate motion at the Pacific-North American plate boundary. PBO Nucleus is a project-within-a-project to incorporate existing GPS networks into the overall PBO observations. Headquartered at UNAVCO, the project proposed a set of particular E/O activities to complement its scientific activities: development of educational materials about GPS and its role in elucidating plate tectonics, and dissemination of those materials to educators at the secondary (middle and high school) and college level through workshops conducted at educational and scientific meetings. Since the project was funded in 2005, these educational materials have been developed by the UNAVCO E&O staff and their collaborators, including educators supported in teacher-in-residence and faculty-in-residence positions. Materials include tools to access and visualize data, informational documents and tutorials about GPS, and classroom activities,

The evaluation team from Ethnography & Evaluation Research (E&ER) was hired to evaluate the impact of these E/O activities to date, and to provide advice for future E/O work that may be conducted on behalf of PBO. To meet that objective, we have conducted two studies, examining two key groups of participants in the E/O activities supported by PBO Nucleus: teachers and scientists.

In this report, we describe the results of a survey of scientists who contributed to these E/O activities in large and small ways. The scientists played a variety of roles: contributing to development of materials or reviewing them for scientific content and accuracy, presenting to educators in the dissemination workshops, and serving on E/O advisory groups. The survey investigated the nature and level of scientists' participation in E/O for UNAVCO and in general, their reasons for participating, the gains they make and the barriers they face, and their views of broader impacts in general. Among the subset of scientists who were also instructors, we investigated their awareness and use of the project-developed educational materials.

A separate report is based on a survey and interview study of K-12 and college educators who participated in the dissemination workshops. Findings address their experiences of the workshops, the outcomes of their participation, their subsequent use of the project-developed educational materials, and their advice for improving the materials and workshops. Examination of student impacts of the E/O work was beyond the scope of work for this project.

We reiterate the dual goals of these two studies, to evaluate the impact of the PBO E/O activities to date, and to provide advice for future E/O work. While our reports on these two studies function as summative findings for a particular grant cycle, we are well aware of the unusual long-term E/O opportunity that is offered by the scientific design of the EarthScope and PBO projects. Thus, it is important to note that we also view these reports as formative advice for the next stages of the overall E/O effort.

II. Methods

A. Terminology

Education is usually defined as the teaching and learning of knowledge, skills, and cultural beliefs through formal (in school) or informal (self-directed) activities. Public outreach activities generate awareness and interest and may also support education (Franks et al., 2006). Either or both may be conducted as part of broader impacts work, as well as other types of activities. In this report, we use the term education and outreach, or E/O, to refer to these activities in the broadest sense. In the survey items, we used the simpler term "outreach" to distinguish it more clearly from questions about the specific activities of the UNAVCO Education and Outreach staff, whom we consistently refer to as "UNAVCO E&O."

B. Survey Development and Administration

Survey questions were developed based on the evaluation questions established for the study, information provided about scientists' roles in E/O efforts for PBO Nucleus, and previous research on scientists' involvement in education (Thiry, Laursen & Hunter, 2008; Andrews et al., 2005; Laursen, Liston, Thiry & Graf, 2007). Twelve questions were developed to address scientists' participation in education and outreach ("outreach"), the benefits and costs to them of participating, their use of educational materials developed by the project, and their views of "broader impacts" as a vehicle for involving scientists in education. Some items also gathered basic demographic information. To keep the survey brief and thus more likely to be completed, numerical ratings and check-off questions were emphasized, but opportunities were also provided to add written comments or explanations. The items were prepared and administered online using SurveyMonkey, a web-based survey tool. A copy of the survey, as administered, is included as Appendix A. In the report, we have generally cited complete survey items as asked, but occasionally, the full survey item is too long to include in a figure. For example, the role

descriptions in Figure 2 are abbreviated in the figure; the actual survey items included a more complete definition of several of the roles.

The survey was administered as follows: In May 2008, an invitation with a link to the web-based survey was e-mailed to all members of a list of 34 participating scientists provided by the UNAVCO E&O office. Email addresses were obtained from web searches for scientists' names and checked with the UNAVCO staff. For clarity in distinguishing them from teachers who attended PBO Nucleus workshops, we refer to all of the participants on this list as "scientists," although a small number were experienced science educators and professional developers who participated as workshop presenters. The survey invitation was sent by the evaluators and emphasized the anonymity and confidentiality of responses.

Personalized follow-up reminders were sent approximately eight days after the initial e-mailing to those who had not yet responded, and again about ten days later. Reminders were stopped once they no longer elicited additional responses. The survey was open for a total of about 1 month, somewhat longer than typical, in an attempt to reach survey participants who were conducting summer field work. This decision was based on the content of automated out-of-office e-mail replies and familiarity with geoscience research practices. In all, 23 people responded to the survey, for a response rate of 66%. This is a very strong response rate for a web-based survey of a professional population (Baruch, 1999).

Survey responses were analyzed with descriptive statistics and by coding write-in responses. The sample size is too small to support tests for statistical significance of group differences between subsets of respondents.

C. Study Sample

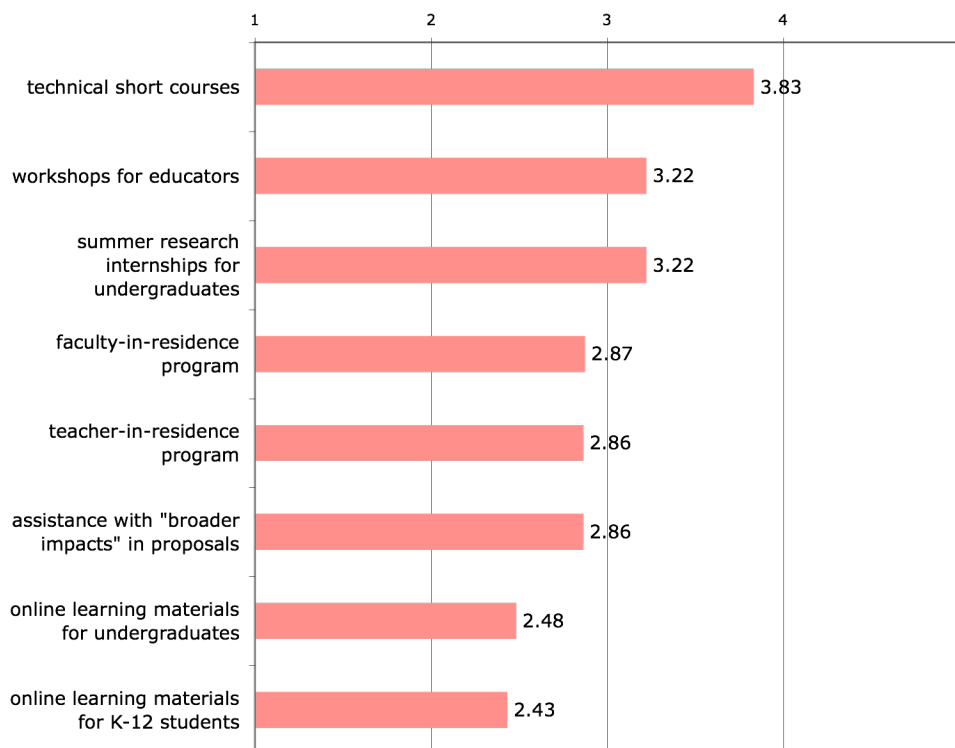
Of the 23 responses received, 16 were from men and seven from women, a gender distribution that matches that in the original population. Half (48%) were college or university faculty, and a third (35%) research scientists. Others indicated their primary professional role to be administrator (9%) or student (9%). The majority (65%) of survey respondents indicated their workplace to be a graduate degree-granting institution. Other workplace types reported included government (13%), non-profit organization (including UNAVCO) (13%), or four-year college (9%). While we do not have comparative data, we believe these characteristics to reflect the general population of the university- and lab-based research scientists with whom UNAVCO interacts. These characteristics also typify a group of scientists whose primary duty is not education, but who are engaged in E&O through their professional connections to the PBO or EarthScope research effort.

III. Findings

A. Familiarity with UNAVCO E&O Programs

As one measure of their depth of engagement with UNAVCO's E&O programs, we investigated scientists' familiarity with these E&O programs, using an item asking them to rate their familiarity with particular programs on a five-point scale. Figure 1 compares the mean ratings for these items.

Figure 1: Familiarity with UNAVCO E&O Programs
(mean rating, with 1 = not at all familiar and 5 = very familiar)



While some of these activities, such as technical short courses and undergraduate research, are not funded by PBO Nucleus, they are among the multiple activities listed on the E&O web page (http://www.unavco.org/edu_outreach/edu_outreach.html). The ratings for the technical short courses offer an internal calibration standard, because they are quite familiar to this group. However, it is worth noting that even the short courses, which might be of greater interest to researchers for their own or junior colleagues' professional development, were rated an average less than 4 on a 5-point scale. Workshops for educators (in which many of the respondents had participated) and undergraduate research opportunities were moderately familiar to respondents. Although the online learning materials have been a major focus of the project's effort, scientists were least familiar with these.

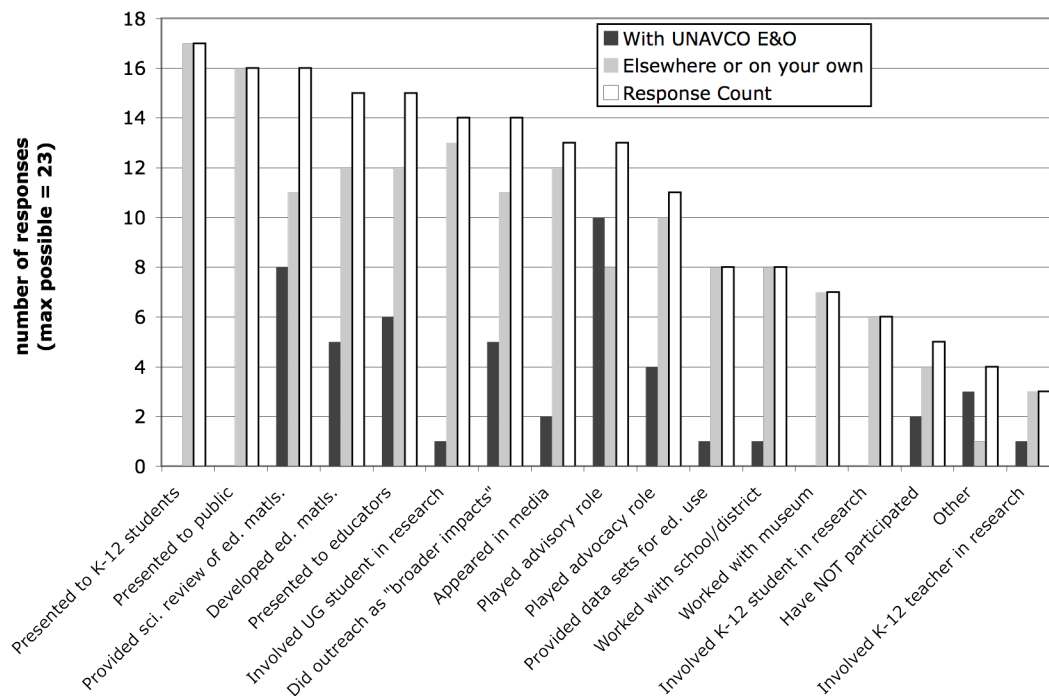
B. Scientists' Roles in Education and Outreach

We asked about the roles scientists played in outreach, providing a list of particular roles (e.g. "Taught or presented to educators") and asking them to check off both their participation with UNAVCO, and their participation "elsewhere or on your own." In general, the responses indicate that a high fraction of the surveyed scientists did participate in E&O related to the PBO

project. The mean number of positive responses to all the items in the checklist was 8.8, with a maximum of 22 and a minimum of 2. Only two respondents indicated that they had participated in *no* UNAVCO-sponsored E&O activities related to PBO Nucleus. Three indicated that they had not participated in E&O activities *outside* of UNAVCO (but these individuals had participated in UNAVCO-sponsored activities).

Figure 2 shows the roles that scientists said they played in E&O activities related to this project, both with UNAVCO (dark bars) and on their own (light bars).

Figure 2: Outreach roles played by scientists



In general, the roles they played for this project were similar to roles they had played before. However, there are some interesting differences in what the scientists did with UNAVCO and what they did on their own. UNAVCO E&O's efforts for PBO Nucleus emphasized development and dissemination of educational materials; the involvement of scientists in this work is reflected in the numbers of scientists who developed or reviewed educational materials, or presented to educators. The most common UNAVCO-related E&O role was advisory, with ten scientists indicating they played an advisory or leadership role—e.g. serving on a board or steering group.

Other E&O roles that scientists commonly took include presenting to K-12 students and to the general public, involving an undergraduate in research, and appearing in the media. The scientists in this study played these roles outside of the UNAVCO-organized effort. Among the "other" responses, scientists listed teaching a technical short course (3), talking with print and radio journalists (1), and leading a field trip at a student conference (1).

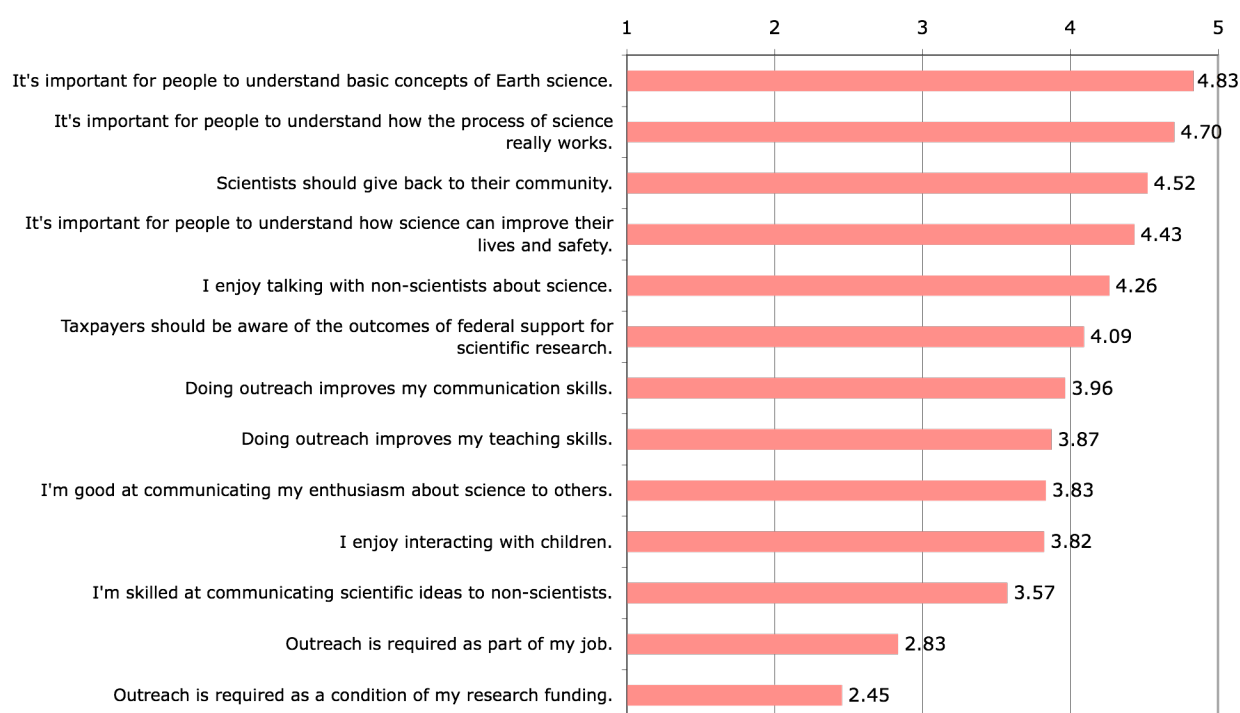
Overall, the type of roles the scientists played are similar to those revealed in other studies (Thiry, Laursen & Hunter, 2008; Andrews et al., 2005). Their high overall activity, and

participation in multiple forms of outreach work, show them to be what Thiry, Laursen and Hunter (2008) have termed “education-engaged scientists”—a group that is of interest because of their active involvement in E/O. Their responses cannot, however, be taken to represent the overall population of scientists. We also note the wide range in activity level—though rarely zero, there is great variety in the depth of scientists’ involvement in E/O, ranging from people who undertake many types of E/O activities to those who are quite selective in their choices.

C. Motivations for Participating in Outreach

We asked scientists about their reasons for participating in outreach in a Likert-style item that asked respondents to agree or disagree with statements reflecting possible motivations. These statements were based on the research literature on scientists’ participation (Andrews et al., 2005; Thiry, Laursen & Hunter, 2008). Results are shown in Figure 3.

Figure 3: Motivations for participating in outreach
(mean rating, where 1 = strongly disagree and 5 = strongly agree)



Three of the top four motivations were based in scientists’ desire to communicate what they know to students and the public: Respondents agreed that people should understand basic concepts of Earth science, how the process of science works, and how Earth science was relevant to their lives and safety. Many also felt a personal obligation to “give back” to society in this manner, the third-ranked motivation. Scientists also enjoyed talking with non-scientists about their work, ranking this highly as well (5th). Enjoyment of interacting with children, in particular, was positive but rather lower-ranked than non-scientists more generally, and four respondents disagreed or strongly disagreed with this statement. Enjoyment from working with children is more often mentioned by graduate students as a motivation for participating in outreach (Andrews et al., 2005) and there are few students in this sample.

Motivations that were rated positively, but more modestly, include the opportunity to improving communication or teaching skills. In other studies, these motivations have been rated highly by graduate students and other early-career scientists (Andrews, et al., 2005; Tanner, 2000), who are not in significant numbers in the survey sample. Also more modestly ranked, though still positively rated as motivations, are scientists' sense of using their particular skills at communicating scientific ideas or sharing their enthusiasm for science. One respondent added an additional reason for participating that was not on our checklist: "To encourage more scientists to become involved."

Two statements received mild negative ratings, indicating disagreement with the statement: those that indicated that outreach was compulsory in some way: required as a part of the job, or required as a condition of one's research funding. These indicate that scientists participate in E/O voluntarily and do not feel compelled by broader impacts requirements to conduct outreach. We address views of broader impacts in more detail later in the report.

D. Effectiveness of Outreach Efforts for PBO Nucleus

We asked scientists to rate the perceived effectiveness of the outreach work in which they had participated, including their personal contribution, the program, and the effort as a whole. Overall, respondents viewed the effort as moderately effective, as seen in mean ratings near 3.6 on a 5-point scale. Table 1 shows the mean rating and frequency distribution of ratings in detail.

Table 1: Ratings of Effectiveness of Outreach Efforts

	Not at all effective (1)	(2)	(3)	(4)	Very effective (5)	Mean rating
Your personal contribution	0	2	8	11	2	3.57
The program(s) in which you have participated	1	0	7	10	3	3.67
The PBO Nucleus E/O effort as a whole	1	2	7	6	4	3.50

The distribution of responses is interesting because of the presence of a few extreme ratings at both the "very effective" and "not at all effective" ends of the scale. The respondent who rated the program in which s/he participated as "not at all effective" is not the same individual who gave that rating to the effort as a whole.

We were interested in scientists' perception of program effectiveness but anticipated that some would respond that they had no evidence about effectiveness. To emphasize that we were inviting their perceptions, we emphasized "in your own view" in the wording of the item, and included an optional, open-ended item asking respondents to comment on the "basis for your views." Several responses on the open-ended item noted limitations in their knowledge, such as:

This is my own evaluation of the short course on strainmeter data, only.

I personally have contributed only a review of a presentation for some lesson plans, so I have had very little outreach experience. Because I am not involved with UNAVCO E&O, I cannot really assess the effects of the program.

Two comments noted their source as informal feedback from participants:

The limited activities I have been involved with got very good feedback from participants.

Most of my views are from informal feedback that I receive at the times of activities; in many cases these are repeated activities.

Another scientist indicated familiarity with the outcomes of a particular program, RESESS: “The RESESS program has had a major impact on the students that have participated.”

Finally, several respondents explained their somewhat qualified ratings of overall effectiveness in their comments. Two of these acknowledged challenges faced by the UNAVCO E&O group

The PBO Nucleus E&O effort has a big challenge. Among scientific researchers in the sciences of crustal deformation, a negative attitude about outreach prevails. Our science consistently ranks very low in measures of diversity and this is reflected not only in a lack of ethnic diversity but a kind of subculture that is very different from, and often contemptuous of, the mainstream. Change will not come quickly. I am impressed by the UNAVCO E&O group's broad spectrum of effort and the creativity with which they approach this.

Although UNAVCO & EarthScope E&O efforts have been underway for a few years, there have been big changes in midstream (e.g. change in operation of EarthScope National Office) that have hampered the effort. I think UNAVCO & EarthScope and others in [the] geoscience education community are just now getting well coordinated.

Another thoughtful commentator pointed out that the overall effectiveness of E/O efforts depended in part on the skills of participating scientists themselves.

I think researchers like myself make important contributions to outreach activities by (1) helping to insure that outreach materials are based on current solid science and (2) by providing an opportunity for students, educators, and the general public to meet and interact with a real live scientist (rather than just reading about scientific discoveries in books or learning about them on TV). However, many of us researchers are not highly skilled in presenting material in a way that's easy for people to understand, be it in a classroom setting, field trip, or casual conversation. Becoming an effective communicator takes time, practice, and effort which is often not required or rewarded by their employers or funders.

In addition to these comments, a separate write-in item invited suggestions for improving the E/O effort connected to PBO Nucleus. Three suggestions addressed a similar theme, their hopes for improved focus and productivity from greater coordination with EarthScope.

I think that PBO Nucleus E&O has been quite successful thus far. It is probably best to focus on doing a small number of outreach activities well than a larger number only adequately. The PBO Nucleus E&O activities also benefit from being an integral part of UNAVCO's broader E/O program.

As with all E/O, trying to assess effectiveness is always difficult and worthwhile to try and improve. Coordination between PBO Nucleus and Earthscope E&O has been worthwhile and should be continued.

Develop more classroom activities for K-16 featuring EarthScope observations and research. This is happening but at a slow pace. I'm hopeful that recently improved collaborations between UNAVCO & EarthScope and others in [the] geoscience education community will result in a more rapid pace of classroom activities development.

A fourth respondent suggested trying some more “radical” ideas, and offered a few examples:

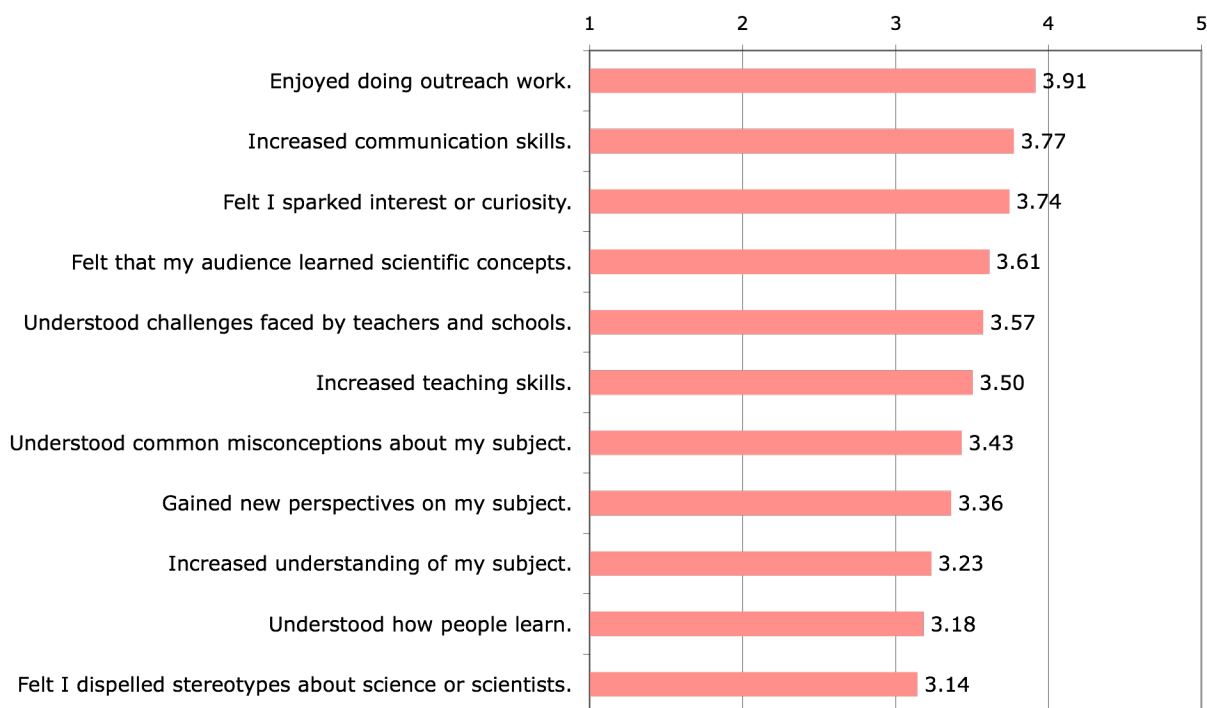
Try some radical ideas. Set up a pilot program whereby high school and community college teachers can do full-fledged NSF-funded research during their summers plus part-time during school years. Develop teaching materials that can be used in math and physics courses, not just Earth science courses. Target professional and technical adults to engage them in our science.

Thus, overall, the scientist participants perceived the program as more effective than not. They also recognized the limitations of their knowledge about effectiveness, and acknowledged some important challenges for the overall effort.

E. Benefits and Barriers to Participation in Outreach

We asked scientists about the benefits that they experienced personally from participating in outreach, as well as the barriers or hindrances to participating that they experienced. In both cases, the survey item presented a list of benefits or barriers that have been reported in the literature (Andrews et al., 2005; Thiry, Laursen & Hunter, 2008; Laursen, Liston, Thiry & Graf, 2007) and asked respondents to rate their level of gain, on a 5-point scale. Figure 4 shows the mean ratings of the benefits reported by scientists.

Figure 4: Benefits of Participating in Outreach
(mean rating, where 1 = no gain and 5 = very high gain)



Enjoyment was the most frequently reported benefit, with all respondents reporting moderate to very high gains (3 or greater) in this area. Gains in communication and teaching skills were highly ranked (2nd and 6th, respectively). Also highly ranked were perceived benefits to the audience—gains in learning and interest or curiosity (3rd and 4th). For example, one scientist wrote:

The review I did was fairly simple and required some fact-checking. Anyone who saw the presentation [with which I helped] would presumably have a better understanding of the subject, though I never really got to see the final product.

Scientists reported modest gains in their understanding of their audiences: appreciating the challenges faced by teachers and schools, coming to recognize common misconceptions about their subject or gaining new perspectives on it, or increased understanding of how people learn.

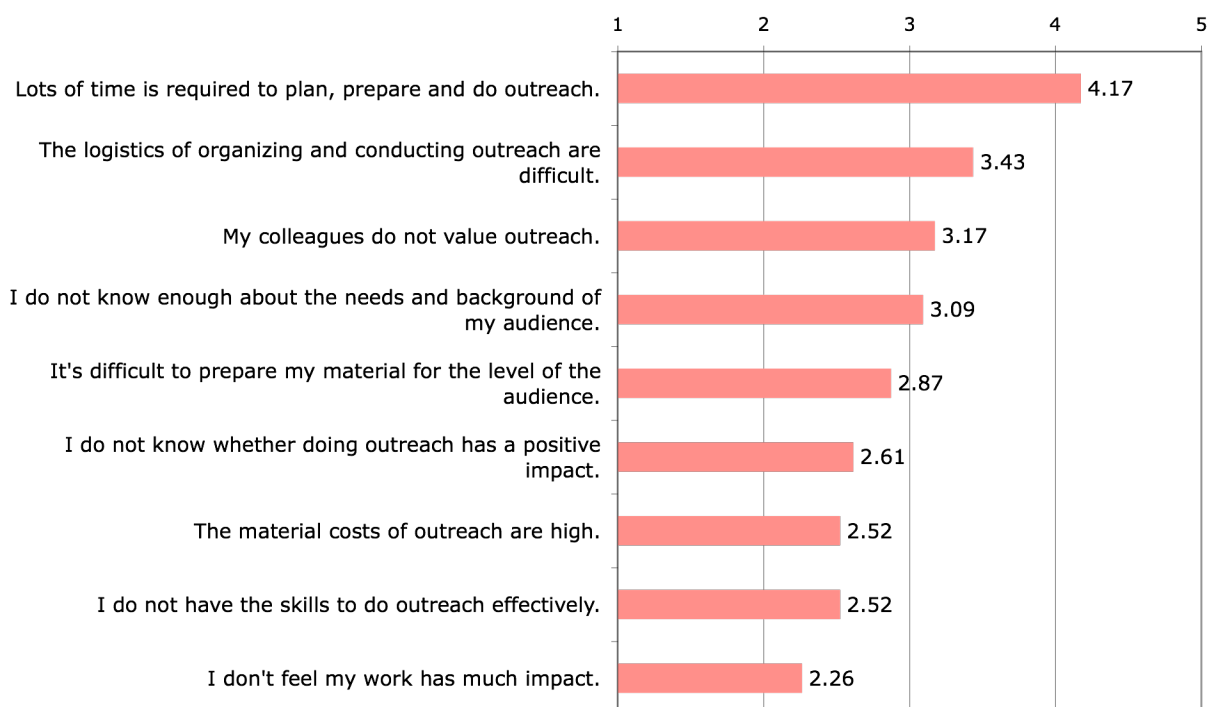
In this study, dispelling stereotypes about science or scientists was the least often reported of all those surveyed (though nonetheless reported at a moderate level by 2/3 of participants). In a previous study (Laursen et al., 2007), scientists reported as an outcome for their audience that they dispelled students' stereotypes of scientists as white and male (Finson, 2002), and altered students' beliefs that science was boring or irrelevant. However, this was observed in a science outreach program which had a majority of female presenters; in the present study, most participants were male.¹ In this study, one scientist did add a note that reflects the mutual benefit of interacting with a wider community:

I enjoy the feeling of being a part of the community where I live, not just a scientist buried in an office staring at a computer. Also, I enjoy meeting a diverse group of people, which my work otherwise does not provide.

Mean ratings of the barriers experienced by scientists are compared in Figure 5. Time to plan, prepare and conduct outreach activities was the most significant barrier, by far, with 18 of 23 scientists rating this barrier high or very high (4 or 5 on a 5-point scale). One scientist noted a specific time issue, disruption to her ongoing work: "Outreach is a bit overstimulating, so it is hard to re-engage quickly with detailed analytical work." Another scientist offered a broader perspective on the level of commitment required: "I now understand that doing E/O well takes money and time. This is an issue in a time of reduced funding." Logistical difficulties were also ranked high. These two issues are commonly reported in the literature as well (Andrews et al., 2005; Thiry, Laursen & Hunter, 2008; Laursen et al., 2007).

¹ We did not ask respondents' ethnicity, but based on photographs on the web pages we researched to identify their email addresses, we believe that few were members of groups generally underrepresented in science.

Figure 5: Barriers to Participating in Outreach
(mean ratings, where 1 = not a barrier and 5 = very high barrier)



Lack of support from colleagues who do not value outreach was the third-ranked barrier. This concern is echoed in the responses to a later item about colleagues' perceptions of broader impacts. We have found elsewhere (Thiry, Laursen & Hunter, 2008) that education-engaged scientists often feel isolated and do not realize that others are also interested in E/O. In that study, a side benefit of professional development opportunities to support scientists' E/O work was the chance to meet other like-minded colleagues.

Barriers perceived as more modest stemmed from several types of uncertainty: lack of knowledge about the needs and background of one's audience, difficulties in adapting material to the level of the audience, and lack of knowledge about the impact of one's work. It is interesting to note that gains in understanding of comparable issues from their E/O work were reported only at modest levels. In our experience, scientists are not always aware of how greater understanding of their audiences might benefit their work. The combination suggests that professional development opportunities addressing these issues might be worthwhile, to lower this barrier and increase scientists' ability to learn from their interactions.

Barriers generally rated as low included lack of skills to conduct outreach well, lack of material resources to use in conducting outreach, and self-doubt about the impact of one's work. This last point is interesting in light of scientists' comments in the previous section about their lack of knowledge about E/O program effectiveness. Though they do not have information about effectiveness, the lack of evidence is not a deterrent to their belief that their work is effective. This point reinforces the role of intrinsic motivations in engaging scientists in E/O work.

F. Use of UNAVCO-Developed Educational Materials

Survey questions about the use of the UNAVCO-developed educational materials were arranged in a branching fashion so that a negative response enabled participants to skip forward to the next pertinent question. For example, if respondents did not teach an appropriate course in which the educational materials might be used, they were not asked to respond to items asking about their use of the materials. Of 23 respondents, 15 taught courses in which learning materials related to GPS and plate tectonics were relevant: 10 at the undergraduate level and 5 at multiple levels (most often, both graduate and undergraduate). Particular courses mentioned were introductory courses for non-science majors on Earth systems and on natural hazards, and geology majors courses on geophysics. Two identified specialized, short or regular-term courses focused on GPS. Two respondents identified courses for K-12 students or teachers: both of these had offered professional development programs in Earth science to K-12 teachers, and one had also taught science courses for students in grades 8-12. The number of respondents who taught courses is larger than the number who are college instructors, indicating (as do the write-in answers) that some researchers teach occasionally in specialized settings such as short courses.

Of the 15 respondents who taught relevant courses, five, or one-third had used the materials. Table 2 shows the frequency of use of several different types of educational materials by those who did use them. The most popular items were web-based visualization tools, online data sets, and informational materials about GPS, such as handouts, student readings, or web-based tutorials. These choices suggest a preference among college-level educators for resources that they can incorporate into their teaching, rather than pre-packaged activities or presentations.

Table 2: Frequency of Use of UNAVCO-Developed Educational Materials
by Scientists who Reported Any Use of the Materials

Educational Materials	Number of users (of 5)
Web-based data display or visualization tools	5
Online GPS data sets for educational use	4
Informational resources about GPS (e.g. handouts, readings, or web-based tutorials)	4
In-class activities	3
Powerpoint lecture slides	2
Fliers or brochures about PBO Nucleus	2
Out-of-class activities or homework assignments	1

Table 2 includes a total of 21 mentions of use by only five scientists. This suggests that the use of materials, once they are discovered, is high. That is, instructors who use the materials at all choose multiple items, suggesting that they are building multiple lessons or a course unit around the topics. However, the overall proportion of users—even among this group of highly education-engaged scientists—is low. This appears to be related to their low familiarity with the materials: Among the 15 instructors who did teach an appropriate course, only seven—under half—ranked their familiarity with the online learning materials as moderate to high (3, 4 or 5 on a 5-point scale). Five of these were also users. Put a different way, of the 10 non-users of the materials, eight indicated that they were not familiar with the materials (1 or 2 on 5-point scale).

While not all instructors will choose to use the materials, becoming aware of them is a necessary first step. Publicizing the materials is one concrete action that could help to recruit new users.

Only two of the five users elected to comment on the materials in an open-ended response. A college educator provided the following evaluation:

In general, the learning materials produced by UNAVCO E&O are of high quality. I never use these materials "as is" but rather adapt to my region and my audience. The quest now should be to ramp up the number of classroom activities while maintaining the high quality.

A user who used the materials with K-12 audiences made the following suggestion about teacher support:

The materials are well-developed and helpful for the most part. In terms of improvement, specifically, when it comes to customizing workshops geared toward audiences (science teachers) that may have less familiarity with cutting-edge science, it is essential to create Teacher Guides and a detailed "background information/Content" for teachers to provide them with in-depth knowledge and other resources to access in order for teachers to feel comfortable teaching the subject matter. Also, it would be beneficial to develop lesson plans geared for middle-level grades (grades 6-9) that teachers can further adapt.

We asked non-users who taught a course to explain why they had not chosen to use them, hoping to elicit critiques from instructors had reviewed but elected not to use the materials. However, only one of the ten instructors who were non-users of the materials answered this question, saying that she not been teaching in recent years. Given that most respondents were also unfamiliar with the learning materials, we assume that they had not, for the most part, reviewed the materials and explicitly chosen not to use them; rather, they had formed no opinion of the materials. This interpretation is supported by responses to another question on whether instructors would use the materials in the future: Ten respondents said they planned to use the materials, five said they might use them, and no respondent said s/he would not use the materials. Two respondents elaborated on their intentions to use the materials:

Materials are useful for K-12 classes I sometimes teach in local schools. I already have lots of material for my undergraduate GPS class.

I would use them not in courses per se, but at open houses, or other presentations. Generally I prepare the materials used in the short course I teach, and UNAVCO makes them available.

Strong response on the future plans item suggests that the survey itself was the means by which instructors learned about the educational materials for undergraduates. Once they were aware that such materials existed, instructors were intrigued and planned to seriously consider using them in their courses. Thus it may be productive to feature undergraduate learning materials, and/or courses that make use of them, in informational media such as the UNAVCO web page, EarthScope newsletters, or other publications that reach EarthScope participants who are faculty.

Moreover, the comment, "I already have lots of material for my undergraduate GPS class," is a reminder that the instructors sampled in this survey are already engaged in geodetic research and education, and may not need educational materials for their own use. Thus, it may be even more productive to make efforts to reach non-EarthScope participants who are less familiar already with this field and may be less able to create teaching materials on this topic themselves.

G. Scientists' Views of the "Broader Impacts" Criterion

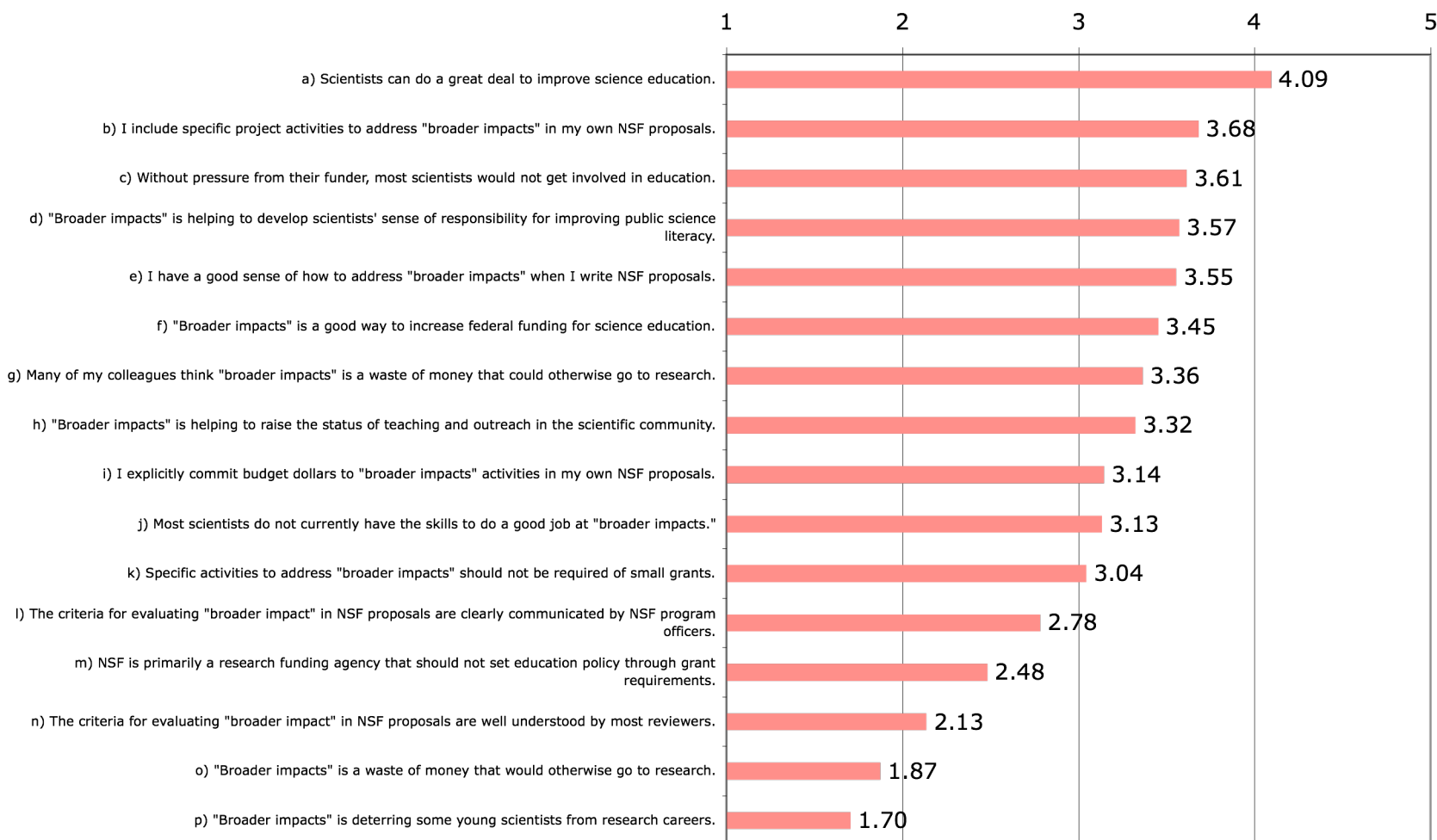
"Broader impacts" is the second review criterion for NSF grants, in addition to "intellectual merit." As noted, NSF requires every proposal to explicitly address the broader impact of the research through contributions to broadly useful data sources, public understanding, education, infrastructure, or efforts to increase diversity. In response, many scientists have begun to include E/O activities in their grant proposals as a way to address broader impacts. Large collaborative projects make a common practice of including organized E/O in their broader impacts work, such as the work studied in this evaluation; strategies for individual scientists in smaller grants are more varied. We have observed shifts in scientists' views and practices, but many practical and philosophical questions remain unanswered as to what constitutes appropriate broader impacts work, whether review panels are well-qualified to evaluate these elements in proposals, and whether this is the most effective possible use of funds. NSF program officers express a wide range of views about their own and panelists' understanding of the criterion and how it is implemented in practice (Mayhew, 2006).

We elicited scientists' beliefs about broader impacts in an item that posed a list of claims to which respondents indicated their degree of agreement on a 5-point scale. The claims addressed scientists' appropriate role in education, their skills and inclination to participate in education, the use of federal research funding and specifically, NSF merit review, to encourage this, and scientists' own "broader impacts" practices. The claims were drawn from various sources, including the research literature on scientists' involvement with education, Mayhew's (2006) survey of NSF program officers, and informal comments made by scientists in our professional development and E/O work with them. To elicit a range of responses, claims were stated in strong forms, and a few "extreme" claims were added. In fact, this item drew the broadest range of responses, eliciting responses across the span from "strongly disagree" to "strongly agree" on nearly every item. The frequency distribution is shown in Table 3 and the means are compared graphically in Figure 6.

Table 3: Agree/disagree Ratings on Claims about Broader Impacts

Claim	Strongly disagree (1)	(2)	(3)	(4)	Strongly agree (5)	Mean
a) Scientists can do a great deal to improve science education.	0	1	3	12	7	4.09
b) I include specific project activities to address "broader impacts" in my own NSF proposals.	0	4	5	7	6	3.68
c) Without pressure from their funder, most scientists would not get involved in education.	0	3	8	7	5	3.61
d) "Broader impacts" is helping to develop scientists' sense of responsibility for improving public science literacy.	2	1	5	12	3	3.57
e) I have a good sense of how to address "broader impacts" when I write NSF proposals.	1	2	6	10	3	3.55
f) "Broader impacts" is a good way to increase federal funding for science education.	2	4	3	8	5	3.45
g) Many of my colleagues think "broader impacts" is a waste of money that could otherwise go to research.	2	1	12	1	6	3.36
h) "Broader impacts" is helping to raise the status of teaching and outreach in the scientific community.	0	5	6	10	1	3.32
i) I explicitly commit budget dollars to "broader impacts" activities in my own NSF proposals.	2	6	7	1	6	3.14
j) Most scientists do not currently have the skills to do a good job at "broader impacts."	2	2	12	5	2	3.13
k) Specific activities to address "broader impacts" should not be required of small grants.	4	4	6	5	4	3.04
l) The criteria for evaluating "broader impact" in NSF proposals are clearly communicated by NSF program officers.	3	6	9	3	2	2.78
m) NSF is primarily a research funding agency that should not set education policy through grant requirements.	6	8	4	2	3	2.48
n) The criteria for evaluating "broader impact" in NSF proposals are well understood by most reviewers.	8	7	6	1	1	2.13
o) "Broader impacts" is a waste of money that would otherwise go to research.	10	7	5	1	0	1.87
p) "Broader impacts" is deterring some young scientists from research careers.	11	9	2	1	0	1.70

Figure 6: Scientists' Views of "Broader Impacts"
 (mean rating, where 1 = strongly disagree and 5 = strongly agree)



The highest level of agreement was reported for claim (a), “Scientists can do a great deal to improve science education.” As might be expected in this sample of education-engaged scientists with personal and societal commitments to E/O, most (19 of 23) agreed or strongly agreed, but three were neutral and one disagreed. Scientists also agreed that broader impacts served as a mechanism for changing scientific culture: most generally agreed that pressure from funders was necessary to get scientists involved in education (c), although they had disagreed that they personally felt this as pressure. They also agreed that cultural shifts were taking place in scientists’ sense of responsibility for communicating their work to the public (d) and in the status of teaching and outreach among scientists (h).

How such cultural shifts come about is suggested by the scientists’ responses about their own broader impacts practices: most (13 of 23) agreed or strongly agreed that they included specific activities in their own grant proposals to address broader impacts (b). However, only half of those who included specific broader impacts activities in their proposals (7 of 13) also committed budget dollars to them (i). This suggests that, even among the strongly education-engaged scientists included in this sample, E/O work to meet broader impacts is still viewed as something that can be achieved as a discretionary or volunteer activity to be done on one’s “own” time. This use of discretionary time to meet obligations to one’s funder may be seen as an acceptable tradeoff because outreach is fun, but it also leads to the experience that time is a significant barrier—both outcomes reported in Section 5. Among those in this sample at least, scientists continue to perceive outreach as an intrinsically rewarding but add-on activity, rather than a professional duty. These data suggest a paradox: scientists feel that broader impacts is beginning to cause outreach to be viewed as an obligation of the profession, but they still personally treat it as a personal commitment rather than a professional duty to be done during work hours.

It is also interesting to examine differences in how scientists perceive the understanding of broader impacts as an NSF review criterion. Most scientists agreed that they personally had “a good sense” of how to address broader impacts (e). Their ratings on this item generally paralleled their own actions: they explicitly addressed broader impacts and felt they understood how to do so. They were nearly neutral about whether most scientists had the skills needed to “do a good job” at broader impacts (j). However, they mildly disagreed that NSF program officers communicated clearly about how broader impacts was evaluated in proposals (l) and rather more strongly disagreed that broader impacts review criteria were well understood by review panelists (n). That is, they feel they understand this criteria well, but do not feel that it is necessarily executed well by other colleagues, communicated well by program officers, or understood well by panelists. As education-engaged scientists, they may view themselves as more experienced than most scientists, perhaps as leaders in developing effective education-related broader impacts components of their grants. Their views are consistent with the spread of opinion of NSF program officers themselves (Mayhew, 2006).

Responses on two other claims also suggest that scientists in this group perceive themselves as outliers among their peers. Most (17 of 23) disagreed or strongly disagreed with the deliberately provocative claim (o), ‘Broader impacts’ is a waste of money that would otherwise go to research,’ but they were more likely to agree that their colleagues felt this way, with only three of 23 disagreeing or strongly disagreeing with the parallel claim (g) about the beliefs of “many of their colleagues.”

We expected general agreement with claim (k), ‘Specific activities to address “broader impacts” should not be required of small grants,’ which is a statement we have heard made by scientists in

conversation. However, this statement generated the widest spread of opinion overall, with opinion nearly equally divided between all five responses from strongly disagree to strongly agree. One scientist commented on this claim, saying that reviewers negatively interpreted the inclusion of specific broader impacts activities on small research grants (e.g. those to individual investigators, as opposed to larger collaboratives):

It is my experience that proposing specific activities for broader impacts does little or nothing to increase the chances of getting funded (for small grants). Also, there is no reward for budgeting for such activities, and perhaps a penalty. [That is,] there may be a “sticker price” penalty, depending on the reviewers you happen to get, but you don't get any credit in practice for including it.

We also expected greater agreement with claim (m), ‘NSF is primarily a research funding agency that should not set education policy through grant requirements.’ Responses on this item also ranged across the full spectrum of agreement to disagreement, though inclined toward disagreement (14 disagreed, 5 agreed, 4 were neutral). Responses on this item seem to indicate that review criteria for science proposals are generally—though not universally—viewed as an acceptable tool in setting social policy.

Overall, our survey respondents expressed more positive views of the NSF broader impacts criterion than some informal discussions had led us to anticipate. This group of scientists seemed to perceive that enforcement of this criterion was an appropriate way to engage scientists in E/O (and other possible broader impacts activities) and to steer resources toward science education—even, most felt, through small research grants. Most took active steps to address broader impacts in their own proposals and felt they understood how to do so. However, they did not yet see that their research peers as a group had a clear understanding of this criterion or that it was consistently communicated by NSF.

IV. Discussion

The survey results show that the PBO Nucleus E/O effort has succeeded in involving a group of education-engaged scientists in its E/O work. Scientists take on roles that directly support the educational activities led by UNAVCO E&O; they also pursue other E/O activities on their own. Consistent with previous reports, they are motivated to participate primarily by intrinsic motivations: a desire to share their understanding of Earth science and the investigative process, a belief that scientists should “give back” to society, and enjoyment of discussing science with non-scientists.

The results also indicate that scientists see positive outcomes from their E/O activities, both to themselves and to their audiences. Scientists feel that they have been successful in communicating new ideas and sparking interest in their audiences. They enjoy E/O work and gain skills and understanding from doing it. They perceive the overall PBO E/O effort as effective and are optimistic about the opportunities to further increase its effectiveness through greater collaboration and coordination across the wider E/O community working in plate tectonics education. By far, the most significant barrier they report is time to do E/O, followed by the logistics of organizing it. While providing more time is not an option, it may be possible to increase scientists’ perception of the value of that time, to increase their sense that their colleagues appreciate this work, and to lower other barriers to their participation. Several indicators combine to suggest that scientists perceive E/O as a voluntary activity, rather than a part of their professional work, and do not feel well appreciated by their colleagues. However,

overall, their views of broader impacts as a tool for encouraging scientists' participation in E/O and sharing resources with education were quite positive. While we do not have direct comparison data, we interpret these views as consistent with a small but monotonic cultural shift over the past decade in the status of E/O work in the scientific community.

Additionally, the results suggest opportunities to further amplify the impact of the project. Survey results indicate that the scientists—even those directly participating in aspects of the UNAVCO E&O effort—are not very familiar with UNAVCO's E&O programs, and particularly unacquainted with the educational materials that have been developed and might be useful to many of them. They do perceive gaps in their knowledge (and to a lesser extent, their skills) for conducting E/O, which, together with information about teachers' needs and perceptions of the workshop experience, might be used as a way to draw them into professional development opportunities to further enhance those skills.

While the literature base on scientists' involvement in E/O is only scant, it is worthwhile to compare the present findings with the available previous work. Across studies, respondents are aware of some gaps in their knowledge and skills, but express a fair degree of confidence in their skills—some of which appears to be unmerited, based on feedback from the educators with whom they work. Thiry, Laursen and Hunter (2008) found that few of the scientist participants attending the ReSciPE professional development workshops had access to other professional development opportunities, and that the ReSciPE workshop tended to enhance their awareness of additional knowledge and skills that would benefit their E/O work. That is, a little knowledge tended to help participants recognize that there was still more to learn. Kim and Fortner (2008), in a survey of Great Lakes researchers, found that scientists were moderately aware of the differences in their views of education and those of teachers. However, their companion study (2007) of educators highlights these differences quite clearly, and shows that from educators' perspective, communication difficulties are more significant than they are perceived by scientists. As several authors have noted, cultural and language differences can inhibit the effectiveness of interactions between scientists and educators (Bower, 1996; Richmond, 1996; Tanner, Chatman, & Allen, 2003).

Kim and Fortner (2008), using Morrow's (2000) framework for scientists roles in E/O, find that most scientists play a role as "resource," providing information, expertise, materials, or facilities, rather than the deeper roles of "partner" and "advocate." The overall roles cited by the scientists in this study also match the "resource" role—the five most frequent roles all involve providing information or expertise. While they also played this role in the PBO E/O effort, it is interesting that several respondents also cited advocacy and leadership roles. We believe that these responses reflect participation on leadership and steering bodies for UNAVCO or EarthScope E/O efforts, rather than primarily school-based advocacy, but it is encouraging to see that several respondents report they are taking leadership roles in the scientific community to assist with or advocate for E/O.

The benefits of working in E/O cited here are quite comparable to prior results, with intrinsic benefits rating highest, such as enjoyment and feeling that one is doing something worthwhile in educating others. Gains in skills and understanding are more modestly rated. It is interesting to consider whether scientists might derive more of these benefits if they had a more developed framework in which to consider their work, grounded in reading or professional development.

Another area where we can directly compare these results with prior work is in the barriers to participating in E/O. The scientists queried by Andrews et al. (2005) identified time as a high barrier to participating, as did the Great Lakes researchers surveyed by Kim and Fortner (2008). However, Kim and Fortner's survey sample identified lack of funding as a high barrier as well, while the results of this study parallel those of Andrews et al. in seeing this as a relatively minor issue. The lack of professional reward systems that recognize and reward E/O was a significant barrier cited in Kim and Fortner's study, and lack of value by departmental colleagues or advisors (for graduate students) was also ranked high among respondents in the study by Andrews et al.. Here, colleagues' lack of value on outreach is cited as the third highest barrier. An additional item probing the lack of professional recognition (which is related to, but distinct from community value) would be a useful addition to future versions of the survey.

Both Andrews et al. and Kim and Fortner indicate that lack of information about how to get involved in E/O is a significant barrier. The present survey did not probe that directly, on the assumption that the study sample of scientists involved already had ample information through their participation with UNAVCO E&O. However, two areas of survey findings indicate that our assumption that participants were well-informed may have been erroneous: first, the view of several respondents that their E/O contributions were very minor: they themselves do not feel highly involved. Secondly, they report low awareness of many of the UNAVCO E&O programs; that alone does not indicate that low awareness is a barrier, but does suggest additional opportunity to inform them and perhaps offer other ways to become involved that may draw scientists in further or provide a better fit to their strengths and interests.

Across studies, findings point to the need for professional development to support scientists in their E/O work (Leshner, 2007). Kim and Fortner (2008) emphasize this need as a solution to several of the issues that they see in their paired studies of scientists and educators. A few examples of such offerings do exist. ReSciPE, Resources for Scientists in Partnership with Education, offers a half-day workshop, "Scientific Inquiry in the Classroom," that focuses on the role of inquiry in K-16 science education and models active learning strategies for engaging students in science. The workshop has been shown to provide new ideas and influence scientists' attitudes about E/O (Thiry, Laursen & Hunter, 2008; Laursen, Thiry & Hunter, 2008). Morrow and Dusenbery (2004) describe an in-depth, multiday workshop offering offered by the Space Sciences Institute.

V. Implications for Future Work

We suggest that the project and its advisors consider the following actions to engage and assist scientists:

- Communicate with scientists about the outcomes of their E/O work. This might include routine sharing of post-workshop evaluations with the scientists who participate in each workshop. Another easy first step is to share this report and its companion piece on the teacher interview study, both specifically with scientists who have participated in the E/O work and more broadly to the PBO/EarthScope community at large.
- Inform scientists about the available educational materials at the college level. While college and university faculty are obviously the main audience for these, other researchers offer specialized short courses for which these may also be appropriate.

- Consider offering professional development opportunities to scientists to support their E/O work and help them connect to like-minded colleagues.

A second set of implications emerges from considering this report together with the teacher interview study findings and our own observations and interactions with the project. While views of the UNAVCO E&O effort are generally positive, the results do suggest that there is room for improvement in the focus and clarity of this effort. It is our sense, drawing on both our observations and the data, that the issues for the PBO E/O effort are less ones of quality of execution, than of establishing clear objectives and taking leadership needed to ensure that each activity helps to achieve those objectives—both at the broad project level, in defining goals and choosing strategies of action, and in carrying out specific activities, such as teacher workshops. While the scientists and teachers do not always articulate this need for clarity directly, we see several indicators that their needs would be met by greater clarity of purpose. And a strong message in the findings from the teacher interview study is the need for focus in the materials and workshops themselves. Greater focus might also help to ameliorate practical issues for the UNAVCO E&O staff, whom we observed to be stretched thin by juggling a large number of activities. Trying to meet the needs of all audiences may in fact satisfy none of them; a deeper impact on a smaller number individuals may be argued to be more meaningful than a small effect on a larger number. We thus suggest that the planning team consider the following actions to clarify and refine the E/O program objectives:

- Use this report as a tool to revisit the program's broad goals and specific objectives and to align its strategies for action with these goals and objectives. It is often helpful to be explicit about a theory of change: Why will taking *this* action help us to accomplish our overall goals? How will *this* strategy solve a problem that we believe is important?
- Use a newly articulated theory of change, in combination with the results of these studies, to make decisions about how best to focus E/O efforts for future PBO-related E/O work.
- Recognize differences between college and K-12 audiences, and between middle and high school audiences, and consider how to target program offerings more directly to the needs of those audiences.
- Assert leadership, as professional geoscience educators, in planning and running workshops that have well-defined learning objectives. Scientists bring useful expertise, but most are not experts on teaching and learning, nor on the needs of K-12 teachers. The UNAVCO E&O staff is encouraged to draw on their own professional expertise, and on the literature, to shape the workshops and to clearly communicate with scientists about their roles and contributions.
- Implement more robust internal evaluation procedures that can be linked to external evaluation. In particular, we suggest that the project standardize its post-workshop evaluation form and monitor these routinely to assist facilitators in planning and refining their efforts and to provide feedback to participants. Routine collation of workshop participant lists will also facilitate future summative evaluation.

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