A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

Volume 5, Apr 2006 - Nov 2007
Issue 1

Getting Unstuck: Strategies for Escaping the Science Standards Straitjacket

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Received: 04/06/06, Revised: 07/31/06, Posted: 09/14/06

The Astronomy Education Review, Issue 1, Volume 5:162-177, 2007

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Abstract

In their well-intended efforts to provide schools with K–12 science curricula related to scientific research, space science education and public outreach (EPO) providers who work with K–12 education sometimes view national and state science standards as constraints to be circumvented. In this article, I call for a broader view of the science standards and discuss how EPO providers can support the goals that the standards articulate. Several strategies are proposed to escape this "standards straitjacket": focusing on inquiry, promoting effective teaching, making connections to other science fields, developing partnerships with experts, and broadening the EPO audience beyond the K–12 schools.

1. WHAT IS THE STANDARDS STRAITJACKET?

In recent years, research funders such as the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) have laid increasing responsibility on the scientific community to contribute to the public understanding of science and to increase the diversity of the scientific workforce. These efforts are intended to support national goals of greater science literacy and equity of access to science education and careers. They have also spawned a new "bridging" profession between science and education, often referred to as education and public outreach, or EPO (Fraknoi 2005)—the profession in which I currently work. As a Ph.D.-trained outreach scientist for a large environmental sciences research institute based jointly in a university and a federal laboratory, I work with local and regional schools to provide curriculum and professional development for teachers in science content, inquiry-based teaching, and assessment. I often serve as a content expert for district- and state-level curriculum and standards work. I work with our institute’s scientists to develop effective EPO efforts for their research projects, and I conduct professional development for scientists and science educators who do such work.

With this perspective, I attended the 117th annual meeting of the Astronomical Society of the Pacific (ASP) in Tucson, Arizona, in September 2005, entitled Building Community: The Emerging EPO Profession. The meeting drew over 350 space science educators, outreach professionals, and education-involved scientists from around the country. Because I work primarily in the Earth sciences, this was my first encounter with the space science education community as a group.

Although I benefited from the meeting in many ways, I was struck negatively by one unintended theme: Several presenters working with K–12 education reflected views of the national and state science standards (Note 1) as unfair constraints to their ability to deliver effective EPO programs. I call this view the "standards straitjacket." "Teachers have to teach the standards," said one presenter. Another apologized for the standards-oriented EPO program he described: "We are, I hate to say it, teaching to the standards." Other speakers clearly gave the impression that they had done an end run around the standards in order to "sneak" their content into the K–12 curriculum.

Astronomy Education Review Editor and 2005 meeting co-organizer Andrew Fraknoi explained to me that many astronomers feel that there is not much astronomy in the standards. The content of the K–12 chemistry standards is not what makes chemists want to get out of bed in the morning, either. But it is fundamental stuff, ideas without which a student could not learn more chemistry. The same goes for physics, geology, microbiology, and any other area of the standards; the content of the standards does not represent the cutting edge, nor the exciting ideas that drew us to the field, but it is basic to a sound understanding of the discipline. Moreover, in addition to the disciplines seeking greater emphasis on their subject in the schools, industries from cattle breeders to coal miners and computer manufacturers also clamor for inclusion in the science curriculum.

Part of the problem is a structural one: "science" as a school subject is not the same as the disciplines we study. If universities are taken to represent the organization of knowledge into disciplines, the mathematics standards represent a single discipline, taught on most campuses in a single department, whereas the science standards reflect many disciplines. On my own campus, the content of the state science standards is represented by nine departments and several major institutes in the College of Arts and Sciences alone, and another six or eight academic units of the College of Engineering represent the technology-related standards. (If you want to argue equal time for disciplines, the engineers have the biggest grounds for complaint.)

Both the research base and conversations with teachers and district science coordinators make it evident that the problem with school science education is not that schools need more science to teach; they need better science. The depth and breadth of the national standards is daunting already, and state standards tend to get even broader (Kendall et al. 1999; Kendall, DeFrees, & Richardson 2003; Hollweg & Hill 2003). Education leaders in fields from arts to geography have similar concerns about coverage and the time needed to address their standards (National Education Commission on Time and Learning 1994, cited in Marzano 2003, 25). Many academic subjects compete for limited class time, as do society’s nonacademic expectations of schools. Yet international comparisons, such as Trends in International Math and Science Study (TIMSS) (Note 2), demonstrate repeatedly the greater success of curricula such as those in Japan and Singapore, where students spend up to twice the time on demanding subject matter as in the typical "mile-wide, inch-deep" American curriculum (Marzano 2003, 26). More is really less; it is no improvement at all to cram additional content into the science classroom.

Thus, the end run is not really the solution, nor is the view of standards as a constraint a perspective that helps to improve science education as a whole. In this article, I argue for a new perspective in the EPO professional community that will enable us to escape what can feel like a standards straitjacket. To escape the straitjacket, EPO programs can use the standards more strategically—most simply, by changing approaches within K–12 education, and more broadly by addressing other audiences beyond K–12 students. As the examples suggest (Note 3), many astronomy educators have already recognized these possibilities and begun to take such approaches, in small and large ways. That some of these approaches are difficult and even idealistic means that creativity, collaboration, and risk-taking will be required to accomplish them. Although this piece was provoked by a space science EPO conference, its message applies equally to other disciplinary EPO communities.

2. ESCAPING THE STRAITJACKET

2.1 Individual Attitude Adjustment: Relax and Take a New View of the Standards

Former astronaut and science educator George "Pinky" Nelson often uses dictionary definitions of the word *standard* as a way to explain the role of the national science standards in K–12 education. First, a standard is "a degree or level of requirement, excellence or attainment." The standards provide a vision of science education for *all* students, not just the elite who will become future scientists and engineers (see Seymour 2002 for a review of changes over time in views of science education). Moreover, the standards do not replace some previous explicit, community-constructed view of the goals of science education; they replace a vacuum, in which most schools and teachers had little help in setting their science education goals. Just as the professional license of an accountant, pilot, or nurse signals that this individual has met competency requirements set by his or her professional community, the science standards spell out society's requirements for excellent science education to enable students to act competently as voters, taxpayers, media and product consumers, community volunteers, donors, and activists, and problem-solvers in their own lives.

Second, a standard is "an acknowledged basis for comparing or measuring; a criterion." Thus, the national move toward assessment is at heart a standards-based movement. If we have defined a bar that students should be able to clear, we are obliged to measure whether they have reached that bar. That measurement is much harder to make for science knowledge than at a track meet, but the task deserves our best effort. Despite the public controversy over high-stakes testing and the unfortunate patterns of teacher- and school-bashing that follow, the goal of standards-based assessment is a worthy one.

Finally, a standard is "a flag, banner or ensign." It is a symbol around which to gather the troops: scientists and science educators, parents, teachers, school staff, and students. The standards call for the importance of science in the school curriculum, because science crucially contributes to the nation's economic health, security, and preparedness for natural disasters. The standards provide arguments in favor of sound science education and the objectives for it.

With these understandings, scientists and educators can help reinforce the standards. We value a scientifically literate public; because science depends on the public coffers for research support, it is in our best interest to have one. Any help for science benefits all; not everyone needs to be well-versed in (your part of the electromagnetic spectrum here) astronomy, but everyone needs to appreciate the practical, intellectual, and aesthetic contributions that science discovery makes to the human experience. Thus, we must be knowledgeable about all the standards, not just those in our own field, and must constantly and critically examine how our EPO projects address these crucial science learning goals. Our work must be not just standards-aligned but standards-based. As a body, the science standards represent a good working outline of a citizen's science knowledge. We thus may need to accept that our personal favorite topic is not the only important topic in the world. Advocating for all science standards is one way to support good science education.

Because the definitions of standards also imply assessment, a second way to support the standards is to educate ourselves about student assessment. Assessments should be built into new K–12 education materials, testing whether students have mastered concepts, not just memorized facts. Some assessments provide feedback useful for helping students to fully realize the learning goals; others can provide evaluative evidence about the success of the program. "Backward design" approaches highlight the importance of clearly defining learning goals from the beginning. Clear goals enable development of appropriate assessments that measure students' mastery of these goals, and only then does the design of learning activities move students toward achieving those learning goals (Wiggins & McTighe 2000).

For statewide assessments, the devil is truly in the details, but there may be opportunities for EPO-involved scientists and educators to participate in shaping those details. For example, I served as a member of a committee to develop assessment frameworks for the Earth and space science section of the Colorado state science standards (see Colorado K–12 Academic Standards 2005) (Note 4). The assessment frameworks identify tasks that students could complete to demonstrate their mastery of each standard at their own grade level, and thus shape both development of the state tests and classroom instruction to prepare students at all grades to master the standards. With appropriate background, EPO providers can contribute to the scientific rigor, inquiry emphasis, and developmental appropriateness of the state frameworks. My participation was also professionally valuable, enhancing my ability to speak as a knowledgeable advocate for inquiry-driven, standards-based school science, and to build networks with school-based educators and state education staff.

This last example is also an opportunity to wave the "flag, banner or ensign." As scientists and members of scientific institutions, we have high credibility in our communities. As Bower (1996) and Bybee and Morrow (1998) have argued, scientists can be particularly influential as spokespeople for science education. Rather than undermining the standards as a whole by quibbling with their details, the standards can be a rallying point for supporting excellent science in our schools.

2.2 Loosening the Bindings: Strategies for Working with K–12 Science Education

With this broadened view of the science standards, several new possibilities emerge for EPO programs that elect to work with K–12 schools. Several of these strategies mind 2005 ASP plenary speaker Philip Bell's advice to let go of our "content obsession." By looking beyond the space-related content standards, we loosen the apparent constraints of the standards and find wiggle room within them.

2.2.1 Focus on Inquiry as a Strategy for Teaching and Learning

Perhaps the most obvious strategy to escape apparent content constraints while staying within the K–12 standards is to focus on inquiry. *Inquiry* is defined in the *National Science Education Standards (NSES)*, 1995, as

> a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results.

Inquiry requires that people identify their assumptions, use critical and logical thinking, and consider alternative explanations. Inquiry appears in the standards in two forms: as a pedagogical tactic, it is a way to help students learn science, and as a content area, it is the understandings and abilities of scientific investigation. Together, these two forms of inquiry support all three goals for all students that the standards lay out:

1. To learn the principles and concepts of science, the big ideas ("learn science")
2. To be able to do science, the procedural skills and mental reasoning abilities needed to carry out an investigation ("learn to do science")
3. To understand the nature of science as a human activity, a way of constructing knowledge ("learn about science")

In the teaching standards, the term *inquiry* refers to an approach to teaching and learning, a way to accomplish the first NSES goal of helping students "learn science" — that is, learn the principles and concepts of physical, life, Earth, or space science. In this pedagogical approach, students are engaged in a scientific question, gather and evaluate evidence to try to answer the question, and communicate and critique their own and others' explanations. That is, students use the processes of science to learn the ideas of science. The education research base firmly supports the effectiveness of this approach to building and organizing knowledge (Bransford, Brown, & Cocking 1999; Bybee 2002). The five essential elements of inquiry are spelled out in the NSES and the supporting volume on inquiry (Olson & Loucks-Horsley 2000). In classroom practice, these elements may be student- or teacher-directed to varying degrees, depending on the topic, the students' prior knowledge about it, and the learning goals (Note 5).

Inquiry, defined as a teaching and learning strategy, is the term most often encountered in education and is used in phrases such as *inquiry-based curriculum* and *inquiry teaching strategies*. Space science EPO projects can support this type of inquiry in two ways. One is already common: many projects embed inquiry teaching and learning approaches within the space science curricular materials that they are developing. For example, "Cosmic Survey" (Note 6) explores preconceptions and addresses learners' ideas about the scale and age of astronomical objects. "Kinesthetic Astronomy" (Note 7) focuses on how movements of the Earth relative to the Sun cause the day, year, and seasons. Activities from the ChemConnections module "What Is in a Star?" teach basic physical science ideas about light, color, and spectroscopy through astronomical questions (Kido et al. 2003). But inquiry-based curricula must also directly support the standards' age-appropriate science content goals, and for some EPO projects, that is the problem. Developing curriculum is not the best EPO option for all projects, and thinking about K–12 education solely in terms of curriculum can lead unwary EPO projects right into the armholes of the standards straitjacket.

However, curriculum materials don’t teach students—teachers do. Another important way to support inquiry teaching and learning strategies is to teach teachers how to use them—not just with new curricula, but with all science they teach. The need is great for professional development courses and workshops that both improve teachers’ content understanding and enhance their ability to teach that content well (Loucks-Horsley et al. 2003). Indeed, research shows that teacher professional development is most effective when content learning is coupled with development of "pedagogical content knowledge," which includes strategies for teaching particular, not generic, content, and approaches to address likely student conceptual difficulties with specific content (Shulman 1987; Kennedy 1999; Banilower et al. 2006; Garet et al. 2001; Porter et al. 2003). EPO providers with content expertise can collaborate with and support school district personnel who have expertise in this area. EPO projects do not have to invent everything themselves; it is cost-effective to help schools to purchase and maintain proven inquiry-based curriculum materials that already exist and to support teacher professional development to use it effectively.

2.2.2 Focus on Inquiry as a Scientific Content Area

The second meaning of *inquiry* as described in the NSES highlights an approach to K–12 curricula that any EPO project could use. In addition to appearing in the teaching standards as a strategy to help students "learn science," inquiry is a content standard of its own, encompassing both the second and third NSES goals: "learning to do" science and "learning about" science. Students should have the abilities to do an investigation of their own and an understanding of how scientific knowledge is constructed.

The abilities of inquiry (what students should be able to do) include:

- Identifying questions and concepts for investigation
- Designing and conduct investigations
- Using technology and mathematics to aid an investigation
- Formulating explanations using logic and evidence
- Analyzing alternative explanations
- Communicating and defending an argument

The understandings of inquiry articulate the nature of science as distinct from other types of knowledge and identify science as a human process of building knowledge. For example, students should understand that, in science,

- Investigations involve asking a question and comparing the answer to what is known
- Explanations emphasize evidence
- Explanations have logically consistent arguments
- Investigations are repeatable by others
- Scientists make their results public, perform reviews, and ask each other questions

Although the abilities and understandings of inquiry are related, they are not the same, and one may be mastered without the other. Indeed, a common failing of laboratory curricula is that they practice inquiry skills in specific contexts but neglect to help students generalize these skills to other investigations of their own or of scientists (Singer, Hilton, & Schweingruber 2005). For example, students using chemical and physical tests to identify white powders need to use their test results not only to rule out possible candidates, but also to realize that such logical processes are quite general to scientific thinking—that used by forensic pathologists to rule out crime suspects or by amphibian biologists to eliminate competing hypotheses for frogs' deformities.

Lack of understanding of the content of inquiry lies at the heart of current public controversies such as the teaching of evolution, federal funding of stem cell research, and application of environmental laws. In the NSES, abilities and understandings of inquiry are organized by developmental level; even the youngest schoolchildren should begin to develop these abilities and understandings (Olson & Loucks-Horsley 2000). Yet these are difficult ideas for teachers, who rarely have direct experience of science as inquiry, nor broad exposure to the nature and practice of science across disciplines. For the most part, teachers have not conducted research, even as undergraduates, and their undergraduate science courses have been fact-heavy and discovery-poor. Public understanding of the nature of science contains significant misconceptions (McComas 1996) and is very different from scientists' own understanding of how science works (Harwood, Reiff, & Phillipson 2002; Reiff, Harwood, & Phillipson 2002). Science EPO projects can be very important contributors in this area by developing classroom activities to foster the abilities and understandings of inquiry and providing opportunities for teachers to discuss them meaningfully with scientists. Activities that are independent of a particular curriculum are particularly valuable because teachers can use them to build students' inquiry skills and understanding and reinforce their application to many areas of science. Encountering them in workshops increases teachers' own understanding of the nature of science.

ASP 2005 presenters James Lochner, Michelle Larson, and Barbara Mattson were alerted to this possibility by a teacher workshop to explore EPO opportunities for the Beyond Einstein project, which addresses fundamental research questions about black holes, dark energy, and the Big Bang (poster PW30) (Note 8). In their words, "The complexity of the science . . . and the cutting-edge technology in the proposed missions . . . make connecting these ideas to the classroom a challenge." The strategy that they are developing in response to teachers' ideas emphasizes inquiry and the nature of science rather than the specific content of their research program.

Inquiry workshops for scientists sponsored by the ReSciPE Project (Note 9) use two activities that emphasize the abilities and understandings of inquiry rather than particular science content. The "black box" from the FOSS "Models and Designs" kit teaches students how scientists investigate and build models of things they can experience only indirectly (Note 10). As students investigate a rattling object inside a sealed plastic box, they develop ideas that can be applied to scientific models from the inner workings of an atom to distant astronomical objects. "The Mystery of the Iceman" (Biological Sciences Curriculum Study [BSCS] 2006) emphasizes the difference between evidence and inference. The slightly creepy story of a frozen Bronze Age citizen intrigues middle schoolers, but no specialized science knowledge is needed to interpret facts about the clothing, weapons, and other artifacts found with the frozen body, and then to create and critique explanations for how these artifacts may have been used.

No matter its research science content, any EPO project can support the inquiry standards by developing new activities for students or focusing teacher professional development on the nature of science—that is, by supporting the inquiry standards on the abilities and understandings of inquiry. Sharing stories of discovery with students and the general public engages audiences, fosters inquiry skills, and shows that science is more messy, human, and exciting than the dry, linear process too often described in textbooks. In sum, EPO projects can support the inquiry standards in two ways. They can support inquiry-based teaching and learning methods, either through developing their own materials that embed these, or through more intensive and localized efforts to develop teacher content knowledge linked with pedagogical content knowledge. EPO projects can also support the inquiry content standards by developing materials and educating teachers on the abilities and understandings of inquiry.

2.2.3 Make Connections to Other Fields

Another way to support K–12 education outside the standards straitjacket is to expand the range of content standards addressed. What connections does the research topic have to the life science standards? What physical science concepts can be taught through astronomical examples or space engineering challenges? Where can Earth science ideas be emphasized and enriched by comparing Earth with other worlds?

The opportunities here are very broad. Every person does not need to understand the Jovian magnetosphere, but she should know something about magnets, and thus a planetary mission to Jupiter may include an EPO opportunity to communicate fundamental physical science ideas through an exciting astronomy "hook." Designing a Mars rover requires knowing some basic ideas about batteries and solar energy. An abstract fact like the speed of light gains relevance when students realize that a radio command will take four minutes to reach the rover from Earth—too slow to prevent the rover from tumbling off a cliff, and thus requiring it to be robotic rather than human-guided from Mission Control on Earth. Space science EPO efforts can use aspects of research to engage students in fundamental science from many disciplines.

Several ASP 2005 presenters shared work that built on content standards other than those in space science alone. Christina O’Guinn and Liza Coe described the Astro-Venture curriculum supplements, which address standards in geology, atmosphere, chemistry, and biology, as well as astronomy (poster PF03). Donald Robinson-Boonstra discussed the Student Observation Network (clinic OW2B), whose modules use big themes—for example, living in space—to address a wide range of science standards through inquiry learning strategies. Robinson-Boonstra also highlighted the differences between standards-driven science education and discovery-driven research science. Recognizing that an EPO effort in K–12 education should address questions important for school science—not likely the same questions driving the research science—is a critical first step.

2.2.4 Collaborate with Excellent Existing Curriculum Developers

This strategy is perhaps the easiest of all: Leave the standards to the experts. By collaborating with and supporting groups who already have expertise in standards-based K–12 education, EPO efforts can take advantage of their expertise and well-developed knowledge of the needs of the K–12 community (Note 11). This is a cost-effective and productive way to leverage science education expertise at a time when less federal grant support is going directly to traditional grants for K–12 education programs.

An exemplar of this strategy is the Great Expectations in Math and Science (GEMS) (Note 12) space science core curriculum sequence presented by Carolyn Willard and Kevin Beals at the 2005 ASP meeting (poster PF18 and workshop WRJ). This collaboration is based at the Lawrence Hall of Science (LHS) at the University of California at Berkeley and supported by several NASA projects, including the Sun-Earth Connection Education Forum, Kepler Mission, Origins Education Forum for Hubble Space Telescope, Solar System Education Forum, IBEX Mission, and other astronomy researchers and educators.

Scientists from these projects provide science advice and help the curriculum developers identify key ideas, while the LHS staff brings expertise in inquiry science and experience with the cognitive development of middle school students. The project benefits from the development, testing, and dissemination experience of LHS and from the established reputation and evaluated success of GEMS materials ("Educational Effectiveness of GEMS") (Note 13). The Challenger Learning Centers (CLCs) (Note 14) are another source of K–12 space science education expertise. CLCs already deliver outstanding experiential education around space science content and can leverage external funding to extend their school programs, teacher workshops, and community events (for an example, see Challenger Learning Center of Maine) (Note 15).

2.2.5 Explore Other School-Based Opportunities

Too often it is assumed that working with K–12 education means curriculum development. This is based in part on good intentions of funders and providers who are trying to help where they see a need. But it is also based on some flawed assumptions about impact: that high numbers mean high impact; that posting curriculum on a Web site puts it in the hands of students in an effective classroom; that online materials are equally accessible to all students. Evaluation protocols for NASA-funded EPO projects can too easily emphasize numbers over quality, but real impact on the quality of science education and equal access to it may require a deeper intervention with fewer people. It may mean supplying a computer lab to an inner-city school before the school's students can use online modules or plot science data on a graph. It may mean offering basic science content courses to underprepared teachers through summer institutes (see, e.g., Northeast Front Range Math/Science Partnership) (Note 16); helping schools to review and select from among excellent existing inquiry-based curricula; providing college scholarships to preservice science teachers; funding an extra teaching position to enable school staff to spend time planning and coordinating their science lessons; supporting a district "inquiry fair"; or providing scientists with released time to visit classrooms through programs such as Community Resources for Science (Note 17), Project Astro (Note 18), and "Journey through the Universe" (Note 19).

To identify and pursue such opportunities, EPO providers need to stay in touch with their local schools and communities, building meaningful partnerships instead of going it alone (Bybee 1998; Alberts 1993). We need to do more listening and less talking. What are the schools' real needs? What is the real impact of elegant online curricula that are technologically inaccessible by the underserved high-minority and high-poverty schools most in need of our help? How can we design and fund small, excellent local programs, not just high-profile national programs? How can we draw on the research and evaluation community to closely study what works and what doesn't? How and where can we share those lessons—including the important lessons from "failed" experiments—in the peer-reviewed literature? Crucially, EPO providers must argue to their funders and institutions that their job is to design flexible EPO programs that meet real national and community needs, even if these may not provide as much PR value. I return to the role of funders and institutions below, but too often as EPO providers, we are too cautious, continuing to pursue EPO strategies that have been financially supported in the past instead of making the case for strategies with potential for greater actual impact.

I challenge both the EPO providers and the funders to think "deep" in this way. As part of the 2005 ASP meeting, I visited one place that might be an inspiring place to start. A Kitt Peak astronomer told me that in 50 years, the observatory has hired only one technical staff member from the local Tohono O'odham Indian tribe on whose land the observatory is located, though the observatory offers a variety of programs to the tribe and hires tribal members in nontechnical jobs. This statistic may be viewed as a failure, but also as a challenge and as a starting benchmark for progress. How might the observatory identify and overcome the educational, financial, and cultural barriers that prevent Native Americans from entering well-paid science, technology, and math (STEM) jobs? What similar opportunities exist in labs and observatories around the United States to develop the diverse human resources of their own community? Such programs might entail not only school science support, but also literacy, family and community involvement, teacher recruitment and training, and children's health and after-school programs.

Additionally, a broad community coalition with multiple resources and talents would be required. They would offer a chance to affect a community deeply, and a remarkable opportunity to learn lessons that could be applied widely to improving the equity of access to STEM education and careers. Although such an effort would require a coalition well beyond the science community, science institutions could play a crucial leadership role.

2.3 Springing Free: Working with Nonschool Audiences

The strategies discussed so far work within the apparent constraints of the science standards. Another set of strategies escapes these binds altogether by changing the focus of EPO programs from K–12 schoolchildren to other audiences. Many audiences would benefit from improved science learning opportunities, and EPO efforts can reflect this spread more equitably. EPO programs for children outside school can provide science activities, equipment, and guest presenters for after-school programs such as scouting, youth clubs, or Math, Engineering, and Science Achievement (MESA) programs that target underrepresented groups. Museums, planetaria, and other informal science groups also reach children outside school hours. These programs can emphasize excitement, investigation, and interest in science and need not be standards based, though the standards may be a useful guide to important and age-appropriate topics. Working with these groups will require making community connections and responding to real needs.

For older learners, research experiences for undergraduates and teachers can provide a science discovery learning experience to strengthen understanding of how science really works or inspire a minority student to pursue a STEM major and STEM career (see Seymour et al. 2004; Hunter, Laursen, & Seymour 2006; and Laursen, Hunter, et al. 2006 for evidence of the benefits to students of undergraduate research). EPO providers can partner with organizations such as the Society to Advance Chicano and Native American Scientists (SACNAS) or the American Indian Science and Engineering Society (AISES) to provide mentoring and professional development opportunities to college and graduate students from groups underrepresented in science. Graduate student fellowships to support science education activities, modeled on the NSF GK–12 programs (National Science Foundation) (Note 20) or the Biological Science Initiative's (BSI's) Science Squad (Note 21) at the University of Colorado at Boulder, can support the professional development of scientists with strong education, public speaking skills, and research skills (Laursen et al. 2004; Laursen, Thiry, & Liston 2005; Laursen, Liston, et al. 2006).

ASP 2005 plenary speaker Lynn Dierking noted that only one-third of the working science knowledge of the general public comes from school, whereas the bulk of this knowledge comes from "free-choice" learning: sources outside school and the workplace. Even children spend more waking hours outside school than inside it; over our lifetimes, we spend less than 3% of our time in formal education. Dierking urged targeting science education to nonschool audiences and using nonschool delivery mechanisms, including the Internet, public TV, museums and libraries, clubs, and hobbies. Many ASP presenters discussed museum exhibits and visitor programs at observatories. Other examples included professional development for National Park Service staff (poster PF09, clinic OF2C), light pollution education for the general public (poster PF24), and family events such as Family Astro (Project Astro) and Sun-Earth Day (workshop WFB). We are only beginning to address the potential in communicating science to these varied audiences, whether families, twentysomethings focused on their careers and social lives, seniors, or groups linked by hobby and recreation interests. As Dierking put it, our goal should be to develop customized lifelong learning plans for our communities.

ASP plenary speaker Jon Miller discussed the importance of audiences that affect science policy-making—decision makers, policy leaders, and the "attentive public" who pursue "citizenship between elections" by writing letters to their congressional representatives and donating to science-related causes. What initiatives can effectively reach and teach these constituencies? One example is the science media workshops conducted by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado at Boulder (LASP Education; Note 22), which provide science journalists opportunities to learn about cutting-edge science and interact with scientists. The program seeks to improve the accuracy and frequency with which science is presented in mainstream and science media, where it can reach the public and policy leaders.

2.4 Getting Help: Envisioning New Roles for Funders and Institutions

Houdini could escape a straitjacket alone, but most of us need help. Whereas some of the approaches outlined are already supported by funders, others require broader thinking by both EPO providers and their funders and institutions. The most fundamental change needed is to view the purpose of EPO as raising science literacy, not just publicizing an agency or particular projects (see also Fraknoi 2005). To realize this change, funders can invite and encourage EPO proposals that are driven by community needs, perhaps very basic ones, rather than by science mission goals. Funders can require grounding in the science education literature to avoid reinventing old wheels. They can support solid evaluation plans to gather data of different types, not just documentation of numbers of people "reached," but evidence that "reaching" had an impact, including qualitative and quantitative studies of immediate and long-term impact. They can take—and argue to their overseeing bodies and boards—a big-picture view of STEM education that fosters innovative, perhaps even risky, approaches, and value failures as a chance to learn along with successes. They must recognize the value of excellent small projects that may be locally big but nationally invisible.

3. CONCLUSIONS

As a community, we know the value of public science literacy and a strong and diverse science workforce for ensuring the health of the scientific research enterprise and realizing the benefits that science brings the nation’s economy, security, public health, and environment. We are increasingly recognizing the ways in which partnerships between science and education can help achieve these goals of science literacy and equity. Innovative funders have already begun to require or encourage scientists’ participation in EPO, and research scientists and institutes have responded with innovation, energy, and enthusiasm. A decade ago, there could have been no conference on the emerging EPO profession. It is now time to take a step toward truly needs-based science EPO efforts. By shifting from discipline-specific learning objectives articulated in the science standards to the broad goals expressed by the standards as a whole, and by choosing strategies to support community-wide science literacy in and outside the schools, EPO providers can sidestep the need to shoehorn our research science content into a standards-driven K–12 curriculum.

Notes

Note 1: Though I primarily reference the National Science Education Standards (NSES) from the National Research Council (1996), use of the term *standards* is general and also includes national science benchmarks from the American Association for the Advancement of Science (AAAS) (1993) and the state science standards.

Note 2: TIMSS. Trends in International Math and Science Study, http://nces.ed.gov/timss/. In this international assessment, U.S. students have routinely scored at a mediocre level compared with students from some countries that spend much less on education, and their relative performance decreases from elementary to high school grades.

Note 3: The selected examples are idiosyncratic and by no means comprehensive. Because my purpose is to express an opinion and not to review the literature, examples are chosen from space science projects with which I am already familiar.

Note 4: Colorado K–12 Academic Standards for Science and Consolidated Frameworks. http://www.cde.state.co.us/index_stnd.htm

Note 5: Olson and Loucks-Horsley (2000) provide a useful matrix showing the essential elements of inquiry and variations in their classroom implementation; a copy can be downloaded from http://cires.colorado.edu/education/k12/rescipe/collection/inquirystandards.html#teaching

Note 6: "Cosmic Survey," Smithsonian Astrophysical Observatory, Cambridge, MA. http://cfa-www.harvard.edu/seuforum/learningresources.htm

Note 7: "Kinesthetic Astronomy Sky Time Lesson," Space Science Institute, Boulder, CO. http://www.spacescience.org/education/extra/kinesthetic_astronomy/index.html

Note 8: References to presentations at the 2005 ASP meeting are cited by poster, talk, or workshop number. The meeting program is available at http://www.astrosociety.org/events/2005mtg/agenda.pdf

Note 9: ReSciPE, "Resources for Scientists in Partnership with Education." http://cires.colorado.edu/education/k12/rescipe

Note 10: FOSS (Full Option Science System) Models and Designs kit. Described online at http://lhsfoss.org/scope/folio/html/ModelsAndDesigns/1.html

Note 11: This approach should be distinguished from teacher-based curriculum development; most classroom teachers do not in fact have expertise in curriculum development. As Pinky Nelson has argued, the common practice of assessing teacher workshops by having teachers develop a lesson plan may not be the most effective way to apply teachers' learning from workshops. The value of alternate assessments, such as reflective writing on new understanding of the science concepts or nature of science, or collegial professional projects such as lesson study (Lesson Study Group at Mills College, http://lessonresearch.net/; Lesson Study Research Group, http://www.teacherscollege.edu/lessonstudy/), is an area where more experimentation and research is needed.

Note 12: Great Expectations in Math and Science (GEMS). http://www.lhsgems.org

Note 13: "Educational Effectiveness of GEMS." http://www.lhsgems.org/educeffectiveness.html

Note 14: Challenger Learning Centers. http://www.challenger.org/clc/index.cfm

Note 15: Challenger Learning Center of Maine. http://www.clcofme.org/

Note 16: Northeast Front Range Math/Science Partnership. http://cires.colorado.edu/education/k12/msp

Note 17: Community Resources for Science: Practical Support for Great Science Teaching. http://www.crscience.org/

Note 18: Project Astro: Astronomers and Educators as Partners for Learning, Astronomical Society of the Pacific. http://www.astrosociety.org/education/astro/project_astro.html

Note 19: Journey through the Universe. http://www.challenger.org/Journey/

Note 20: National Science Foundation, NSF Graduate Teaching Fellows in K–12 Education. http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5472&org=DGE&from=home

Note 21: BSI Science Squad, http://www.colorado.edu/Outreach/BSI/k12/sciencesquad.html

Note 22: LASP Education Journalist Workshops. http://lasp.colorado.edu/education/journalists/index.htm

Acknowledgments

I thank Marsha Barber, Annette Brickley, Susan Buhr, Roslyn Dauber, Nancy Kellogg, Samantha Messier, and Lesley Smith for helpful comments on this article.

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