Genetics Education

Innovations in Teaching and Learning Genetics

Edited by Patricia J. Pukkila

Strategies for Avoiding Reinventing the Precollege Education and Outreach Wheel

Erin L. Dolan,* Barbara E. Soots,† Peggy G. Lemaux,‡ Seung Y. Rhee§ and Leonore Reiser§,1

**Fralin Biotechnology Center, Virginia Tech, Blacksburg, Virginia 24061, †Department of Plant Pathology, University of California, Davis, California 95616, ‡Department of Plant and Microbial Biology, University of California, Berkeley, California 94720 and §The Arabidopsis Information Resource, Carnegie Institution of Washington, Department of Plant Biology, Stanford, California 94305*

Manuscript received May 16, 2003
Accepted for publication January 14, 2004

ABSTRACT

The National Science Foundation's recent mandate that all Principal Investigators address the broader impacts of their research has prompted an unprecedented number of scientists to seek opportunities to participate in precollege education and outreach. To help interested geneticists avoid duplicating efforts and make use of existing resources, we examined several precollege genetics, genomics, and biotechnology education efforts and noted the elements that contributed to their success, indicated by program expansion, participant satisfaction, or participant learning. Identifying a specific audience and their needs and resources, involving K–12 teachers in program development, and evaluating program efforts are integral to program success. We highlighted a few innovative programs to illustrate these findings. Challenges that may compromise further development and dissemination of these programs include absence of reward systems for participation in outreach as well as lack of training for scientists doing outreach. Several programs and institutions are tackling these issues in ways that will help sustain outreach efforts while allowing them to be modified to meet the changing needs of their participants, including scientists, teachers, and students. Most importantly, resources and personnel are available to facilitate greater and deeper involvement of scientists in precollege and public education.

THE last decade has brought genomics and biotechnology, fields grounded in genetics, into the public eye through the pages of our newspapers and television screens. Yet, for the most part, the public has little understanding about the underlying scientific concepts. The term "genomics," although coined more than a quarter of a century ago (Lederberg and McCray 2001), is not widely used in the lay press and certainly not widely understood. As the genetic basis of many human diseases is revealed, the use of genomics and biotechnology for diagnosis and treatment becomes more personal and relevant. Thus, these fields are ripe targets for precollege and public education. How do we encourage the general public to better understand genetics so that they can make informed decisions as voters, consumers, and healthcare users? K–12 schools provide the perfect venue for enhancing public awareness and understanding of science, especially genetics. Understanding the molecular basis of heredity and biological evolution is a national science education standard, the minimum expectation for a graduating high school student (National Research Council 1996a). The process of scientific inquiry and the nature of science are also national standards (National Research Council 1996a). Who better understands the how and why of science than a practicing scientist?

Clearly, scientists have resources and expertise to offer to the K–12 community—but how do scientists themselves benefit tangibly from such interactions? There are several compelling reasons to engage in outreach: participation in the development of a scientifically literate citizenry, improvement of teaching skills, communication with a broader audience about research, and learning about education theory. To encourage meaningful involvement in outreach, funding agencies have begun to enforce a stipulation that their grantees participate in public education. For example, in January 2000,

[1] *Corresponding author:* The Arabidopsis Information Resource, Carnegie Institution of Washington, Department of Plant Biology, 260 Panama St., Stanford, CA 94305. E-mail: lreiser@acoma.stanford.edu

the National Science Foundation (NSF) revised its Grant Proposal Guide to specify that Principal Investigators must address not only the intellectual merit of their proposed activities, but also their benefits to society, the broader impacts (examples of activities demonstrating broader impacts are available on the NSF website at http://www.nsf.gov/pubs/2003/nsf032/bicexamples.pdf). The broader impacts of a research effort can manifest themselves in many ways, including the promotion of teaching, training, and learning, as well as the enhancement of public understanding of science and technology.

There has been very little systematic study of genetics outreach programs, although a good number exist across the country (see Table 1). However, simple guides have been assembled for scientists interested in designing K–12 educational materials (Wormstead 1999). In addition, elementary science education partnerships have been examined to determine key factors that contribute to partnership endurance. One of the strong predictors of partnership success, assuming endurance is an indicator of success, is the participation of a strong resource professional, in many cases a scientist, who generates ideas, works well with children, prepares activities in advance, gathers resources, provides content knowledge, and is enthusiastic (Jenkins 2002). Commitment by all partners, commitment to science education and the content area, and benefits for the children are also strong predictors of partnership endurance (Jenkins 2002). Further study to identify factors contributing to outreach program success in the materials- and skills-intensive fields of genetics, genomics, and biotechnology is crucial as more of these efforts are initiated.

Many scientists, educators, and outreach personnel across the country are already successfully partnering to enhance the scientific content of their outreach efforts and to facilitate understanding of research through public education. Other scientists are interested in precollege education and some of them are choosing precollege education as a profession but do not know how to develop a program and are unaware of existing resources that would help them address issues and avoid duplicating existing efforts. We examined several existing precollege education programs in genetics, genomics, and biotechnology to identify the features that help these programs succeed and share the lessons learned by project personnel. We describe these findings here to entice more scientists to get involved in outreach and to avoid common problems.

APPROACH

We assembled a group of 16 scientists, teachers, and outreach professionals involved in precollege genetics education programs who represented various professional backgrounds: practicing geneticists (six); practicing teachers (three); outreach personnel who are biologists by training (six); and one outreach professional who is a teacher by training (see Table 2). In the context of this informal meeting, we asked each person to describe his or her program, including goals, motivations, methodologies, needs addressed, anticipated outcomes, and evaluation strategies, as well as lessons learned. Field notes of project descriptions and subsequent discussion were reviewed to identify characteristics of successful efforts, as well as to determine the overarching issues and strategies used to address them. We assume that repeated and expanded participation by teachers, students, and scientists, satisfaction reported by participants, and participant learning signify program success. To highlight innovative programs in precollege genetics education and illustrate the characteristics that aided in their success, we describe several examples below.

FINDINGS AND EXAMPLES

Identify an audience and their needs and resources: First and foremost, successful programs clearly define their goals and target audience, taking into account the specific needs of all stakeholders—students, teachers, and scientists. The Partnership for Research and Education in Plants (PREP; http://www.biotech.vt.edu/outreach/partnerships.html), created by a high school biology teacher, a plant geneticist, and an outreach coordinator, and administered through Virginia Tech's Fralin Biotechnology Center, was initiated in response to student, teacher, and scientist requests. High school students and their teachers requested opportunities to collect real biological data, instead of conducting lab activities with predictable outcomes or experiments in which no one outside of the classroom is interested. Scientists requested assistance in determining the functions of different genes in the model plant, *Arabidopsis thaliana*.

PREP teachers and scientists guide high school students in designing and conducting their own experiments to study the functions of different genes in plant growth and development. Teachers provide day-to-day guidance for the students on setting up experiments, collecting and analyzing data, and preparing final presentations. Scientists provide materials for growing plants, advice on experimental design, and information about plant biology, genetics, and genomics, either in person or by e-mail. Students then share their original research with their peers, their families, and research scientists at a project-end conference and through minilab reports. Participating students and teachers learn the process of scientific inquiry while providing data for their partner scientists, and scientists learn new information about the plants while providing experimental know-how and up-to-date content and skill knowledge to students and teachers.

Expanding numbers of students, teachers, and scientists participating in PREP are evidence of program suc-

TABLE 1

Genetics, genomics, and biotechnology outreach programs

Nationwide	Biotechnology Institute
Regional	SEE Biotech: Social, Ethical, and Economic Impacts: Iowa, Minnesota, North Dakota, South Dakota, Wisconsin
Alabama	Center for Community Outreach Development, University of Alabama, Birmingham
	Science Education Outreach, University of Alabama, Huntsville
Arizona	BIOTECH Project, University of Arizona
	Biology Project, University of Arizona
Arkansas	Partners in Health Sciences, University of Arkansas for Medical Sciences
California	Bay Area Biotechnology Education Consortium
	Science Achievement in Biology, San Diego State University
	Science and Health Education Partnership, University of California, San Francisco
	Biotechnology in the Classroom, Partnership for Plant Genomics Education, University of California, Davis
Colorado	Biological Sciences Initiative, University of Colorado, Boulder
Connecticut	Connecticut's BioBus
Delaware	Molecular Biology Through Inquiry, University of Delaware
Florida	Center for Precollegiate Education and Training, University of Florida
Georgia	K–12 Outreach, Georgia Tech/Emory Center for the Engineering of Living Tissues
Iowa	Office of Biotechnology, Iowa State University
Kentucky	Biotechnology Research and Education Initiative, University of Kentucky
Maryland	Education Programs, MdBIO
	Education and Training Department, The Institute for Genomic Research
Massachusetts	Citylab, Boston University School of Medicine
Minnesota	SEE Biotech, University of Minnesota
Missouri	Science Outreach, Washington University, St. Louis
Nebraska	Ag Biosafety Education Center, University of Nebraska, Lincoln
New York	Dolan DNA Learning Center, Cold Spring Harbor Laboratory
	LIGASE: Long Island Group Advancing Science Education, SUNY Stonybrook
North Carolina	DESTINY Mobile Lab, University of North Carolina, Chapel Hill
	Fungal Genomics Laboratory, North Carolina State University
	The Science House, North Carolina State University
Ohio	Biotechnology Education Initiative, Ohio State University
South Carolina	Division of Genetic Education, Greenwood Genetic Center
Tennessee	*C-fern* Project, University of Tennessee, Knoxville
Texas	BioTech, University of Texas
Utah	Genetic Science Learning Center, University of Utah
Virginia	Fralin Biotechnology Center, Virginia Tech
Washington	Washington State Genetics Outreach Education Programs
	Fred Hutchison Cancer Research Center Educational Opportunities
Washington, DC	DNA Goes to School/El DNA va a la Escuela
	Discovery Center for Cell and Molecular Biology, Catholic University of America
Wisconsin	BioQUEST

Outreach and partnership programs that specialize in precollege biology, genetics, or biotechnology education. The list is not intended to be comprehensive, but to highlight a number of existing efforts that could serve as resources for interested geneticists. Because such programs often receive state funding, most can provide services only to state residents. URLs can be found at http://www.biotech.vt.edu/outreach/programs.html.

cess in multiple aspects (Figure 1). Each year, more students and teachers engage in designing original experiments and collecting real data. One teacher comments:

> When we first heard about the PREP program, we saw it as an opportunity to provide a structured research experience for our students . . . Our students agree with our assessment. The students involved with the project this year are more confident of their abilities (to design and conduct experiments independently). They are eager to design and carry out their own experimental research next year.

More scientists are also participating in PREP each year (Figure 1) because they value the opportunity for students to conduct experiments with novel outcomes, because the program has the potential to add to the body of knowledge about Arabidopsis, and because they can meet professional expectations for participation in outreach (F. Tax, University of Arizona and B. Winkel, Virginia Tech, personal communication). Although geneticists can join existing programs like PREP, partnerships can also be created to meet individual needs. Individual partnerships are sometimes initiated because the

TABLE 2

Glossary of science education terms

Assessment	Measurement tools such as questionnaires, interviews, surveys, pre- and post-tests, and others.
Evaluation	Systematic study using qualitative and/or quantitative assessments. Examples include program evaluation (Was the program conducted in accordance with its goals and objectives? Were its goals and objectives achieved?) and outcomes evaluation (How are participants changed by participating in the program?).
Matrix	Layout or alignment of concepts and skills with respect to standards at a point within a semester- or year-long curriculum, grade level, and/or assessments. Matrices are often used to help teachers and administrators design curricula within and across grade levels, especially to determine the amount of time or attention to be spent on a given concept or skill.
Outreach	Efforts by colleges, universities, research centers, museums, or science centers to provide technical, material, or personnel resources to precollege education settings, both formal (in classrooms with teachers) and informal (in museums, science centers, and science clubs with informal educators).
Outreach personnel	Personnel whose primary responsibility is to facilitate interactions and share resources among K–12 students, their teachers, and research scientists.
Pedagogy	Teaching approaches and methodologies. Much science education research supports the idea of content-specific pedagogy, wherein particular content and skills are taught using certain content-specific methodologies (*e.g.*, scientific inquiry is best taught by engaging students in designing and conducting experiments; see Bransford *et al.* 1999).
Science educator	Personnel whose primary responsibility is teacher education.
Scientific inquiry	The process of asking and answering questions to better understand scientific concepts by designing and conducting experiments. Classroom inquiry can take many forms depending on the extent of direction by the teacher (*i.e.*, What guidelines does the teacher provide?) *vs.* the students (*i.e.*, How much autonomy do the students have?).
Standards	Specific content and skills that a student is expected to know after completing a course or by a certain point in their education. For an in-depth discussion about standards, see the Winter 2002 issue of *Cell Biology Education* (http://www.cellbioed.org; Tanner and Allen 2002).
Teacher	Person whose primary responsibility is direct instruction of precollege students.

There is endless debate among scientists, science educators, and other professionals about how to define these terms, as well as entire fields dedicated to their study. For the purposes of this article, we have defined them above.

scientist's interest in expanding the science education of their own children. For several examples of individual outreach efforts, see Table 3.

Involve teachers in program development and implementation: Another hallmark of successful programs is that they include K–12 teachers in their development. Teachers not only have practical classroom experience, but also have pedagogical knowledge (*e.g.*, what concepts need to be addressed and when; how to teach a concept or skill in a variety of ways; how to frame details within a larger concept; how to make abstract concepts concrete, etc.). Teachers are familiar with school district and state guidelines (what should be taught to whom and when) and with national science and technology education standards (American Association for the Advancement of Science 1993, 1990; National Research Council 1996a). By involving teachers early and often in program development, one can reduce the risk of developing a program that is irrelevant and, therefore, unused by schools. Teachers ensure that outreach efforts are practical: the lessons developed are cost effective and easy to distribute. More importantly, however, teachers remind us that lessons must be engaging to students by involving them directly in the lessons and by being relevant to their everyday lives.

The Web-based Inquiry Science Environment (WISE) project at the University of California at Berkeley (http://wise.berkeley.edu) heavily involves teachers in development and dissemination of science curriculum (Lachtermacher and Hines 2002). Each online unit includes learning goals and lesson plans, as well as a series of online activities that prompt students to reflect on their own ideas, think through science problems and controversies, understand the underlying science

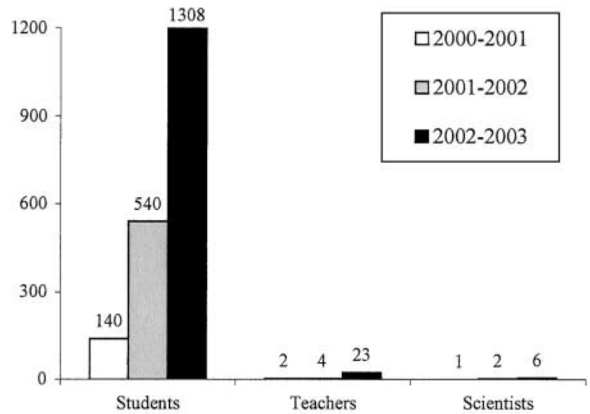

FIGURE 1.—Increased student, teacher, and scientist involvement in PREP. The number of students, teachers, and scientists participating in PREP has increased each academic year of the program (2000–2001 represented by open bars, 2001–2002 represented by shaded bars, 2002–2003 represented by solid bars; actual values noted over each bar). We assume that increased participation is an indicator of participant satisfaction.

concepts, and defend their thinking through online debate (anonymity is optional). For example, a science educator collaborated with a group of middle school science teachers to develop a WISE unit on genetically modified foods, titled "Genetically Modified Food in Perspective." Through a series of prompting questions and accompanying hints, students examine real-world evidence and analyze current scientific controversies regarding genetically modified foods. According to one science educator,

> Start by addressing ideas students bring to class, for example: How widespread is the use of GMOs (genetically modified organisms) or their penetrance in the market. Most people are not aware how much GMO is in food products already..

In addition, support networks for teachers, including accompanying professional development workshops to introduce teachers to the materials and, in some cases, support in the classroom, help ensure successful implementation. Teacher professional development takes many forms, ranging from 1-hr presentations at science education conferences to week-long workshops to semester-long coursework to summer internships (NATIONAL RESEARCH COUNCIL 1996b; LOUCKS-HORSLEY *et al.* 1998). Short presentations or demonstrations may engender teacher interest and excitement. In contrast, week-long workshops often focus on incorporation of content and/or skills into the classroom. Coursework provides college credit that teachers can use to update their content and skill knowledge, as well as fulfill professional development requirements. Research experiences for teachers (*e.g.*, NSF's RET Program) encourage long-term collaboration between teachers and scientists and greatly increase the confidence level of classroom teachers tackling current science topics, including molecular genetics and genomics (NATIONAL RESEARCH COUNCIL 1996b; LOUCKS-HORSLEY *et al.* 1998).

Finally, teachers can aid in disseminating resources they consider valuable, providing an implicit endorsement. This occurs in the PREP program, described above, and in the Partnership for Plant Genomics Education (PPGE) program at the University of California at Davis (UC Davis; http://ppge.ucdavis.edu). PREP teachers have encouraged their colleagues to implement PREP with their students by introducing them to the program via school-district-based workshops and collaboration (*i.e.*, a participating teacher mentors a teacher who is new to the program as they implement PREP with their students; Figure 2). Seventeen teachers became involved in PREP in 2002–2003 as a result of contact by participating teachers, not by contact with PREP personnel. In a more formal approach, the PPGE program requires that teachers participating in their workshops conduct workshops back at their own schools or districts, expanding the number of teachers reached by 10-fold (Figure 2).

Evaluate the effort: Finally, successful programs regularly conduct evaluations to gather feedback from participants to make informed revisions. Evaluation of the PPGE internship program demonstrates this point. This high school laboratory internship program is designed to encourage students from groups traditionally underrepresented in the sciences to explore careers in molecular biology and genomics and for them to develop scientific inquiry and communication skills. Such one-on-one programs require a significant investment of time, materials, and funds and thus are fairly uncommon. However, their impact can be quite significant. Assessment of the UC Davis program revealed that participating students frequently report that the internship experience is one of the most important and rewarding aspects of their high school careers. Of the 21 students who participated in the internship program between 1995 and 2002, 10 went on to enroll at UC Davis in a biological-science-related field and 6 rejoined their mentor's laboratory as a student assistant. One student comments: ". . . this chance for me to do the internship really helped me [to choose] my major for college. I will be going to UC Davis next year, and major[ing] in Biotechnology."

In 2003, the internship program was expanded into a more formal training that included a 1-week orientation workshop to brush up on lab skills, learn about biotechnology and genomics concepts, and review safety procedures. For the 6 weeks following the workshop, students worked in their mentors' laboratories. The internship concluded with a poster session. Students created scientific posters reflective of their work over the summer and gave brief presentations to an assembled group of their peers, mentors, and parents. Benefits to student interns are clear. Interns learn to communicate their ideas with both scientists and their peers. They develop

TABLE 3

Individual partnerships and outreach

Example 1	A plant geneticist at the University of Wisconsin approached teachers at Madison West High School (http://www.madison.k12.wi.us/west) to find students to help conduct experiments as part of her Plant Genome Research Program grant. In turn, the teachers developed their own expectations for the partnership: opportunities for their students to do "real" science, learn about scientific inquiry, and improve their scientific literacy (*e.g.*, What is genetic engineering? What is genomics?). The scientist supplied mutant and wild-type plant seeds for the students, defined a set of growth environments, and demonstrated how she collects data. With the teachers' help, the students then grew plants, collected data about plant growth and development, and reported their findings back to the scientist.
Example 2	Scientists often become involved in K–12 education through their own children's schools. In some cases, these informal interactions can blossom into sustained relationships among the scientist, teachers, and students. Sarah Hake, an adjunct faculty member at the University of California at Berkeley, directs the Plant Gene Expression Center in Albany, California. In the late 1980s, she and her son's science teacher, Don Jolley, were awarded an American Society for Cell Biology grant for Jolley to spend a summer in Hake's lab where she studies plant development and genetics. The grant included a small equipment budget that Jolley used to buy a microscope and camera attachment. During the school year, the pair set up experiments with Jolley's sixth-grade students, including Hake's son. They used the microscope extensively, observing mitotic figures in root tips as well as simpler plant phenotypes. Hake and Jolley continued to collaborate even after both of her sons finished sixth grade, and Hake expanded her effort to work with seventh- and eighth-grade classes. The older students performed experiments of their own design such as growing Arabidopsis in different environmental conditions to assess their physiological responses. The projects often utilized research materials from her own lab such as maize mutants and plants expressing cell-specific markers. Hake also encouraged her lab members to participate in K–12 education, often inviting graduate students to work with the middle school students. When asked why she continued to work with Don and his students, she responded: "I was awed by his teaching powers. I learned how to explain things better working with Don. I also loved getting to know the youth of our town and when I see them in town, they all say 'Hi.' They can also share their experiences of 'recombinant DNA' with their parents and thus defuse the scary myths."
Example 3	Marty Yanofsky is a professor of biology at the University of California at San Diego where his group studies the molecular mechanisms of flower and fruit development. He and a colleague, Ethan Bier, developed an undergraduate course on plant and animal development, including the social and ethical implications of biotechnology and genetic modification. They became interested in sharing this information with the broader community, especially children, because of their belief that people need to be knowledgeable about the underlying biological concepts to be able to make informed decisions about complex issues such as human cloning and genetically modified foods. Yanofsky and Bier both had elementary-school-age children and felt that even young students could begin to understand genetics concepts. Using their scientific expertise and experiences with their own children, the pair presented concepts at a level suitable for elementary students using a hands-on experimental approach that would be both fun and informative. For example, students saw how their grandparents' characteristics could "disappear" in their parents and then reappear in themselves. The students followed the segregation of mutant and wild-type characteristics in fruit flies and plants to see the same principles at work in animals and plants. They also isolated DNA from broccoli to see the molecule underlying this phenomenon. Yanofsky and Bier are frequently asked: Is DNA safe to eat? They respond by asking the students: Where did you isolate it from? Yanofsky and Bier think that this dispels some of the fears about eating genetically modified plants. They hope that these efforts will help children and, ideally, their families better understand and make informed decisions about topics that affect their lives and perhaps spark a young child's interest in science.

marketable lab skills, learn to ask productive questions, design experiments, and analyze results. Moreover, they gain exposure to the university community, make valuable personal contacts, and explore the possibilities of a career in science. Nine students participated in the 2003 summer internship program, and all nine said that the experience influenced them to consider science as a career option. Eight of the students said that the orientation workshop helped make them feel better prepared to work in the laboratory with their mentor. All said their mentors were always available to provide direction and answer questions.

Internship programs benefit mentors as well. By articulating ideas to a lay audience, mentor scientists can

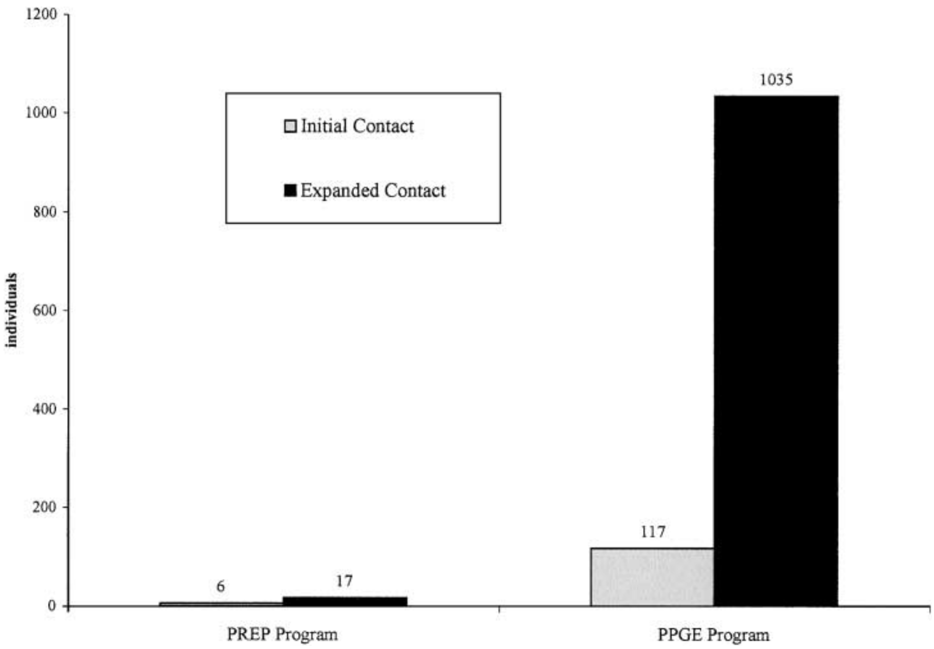

FIGURE 2.—Teacher involvement in program dissemination increases the number of participating teachers. In both the PREP and PPGE programs, participating teachers were recruited by the program personnel (initial contact represented by shaded bars). These teachers recruited additional teachers to participate (expanded contact represented by solid bars) through school and district workshops and mentoring (*i.e.*, a participating teacher mentors a teacher who is new to the program as they implement the program with their students). Actual values are noted over each bar. We assume that teacher recruitment of colleagues is an indicator of their satisfaction with the program.

improve their communication skills as well as their methods for teaching younger, inexperienced scientists. The mentor-student relationship fosters open discussions about possible options for the student's career path, with the added value of the mentor's experience and insights. When asked what they enjoyed most about the program, one mentor responded: "Meeting and teaching someone relatively new to science. Experiencing the enthusiasm of a future scientist."

The evaluation also revealed that recruiting and retaining scientist mentors is the most critical component of the program. To address these issues, the UC Davis program provides logistical support to help alleviate some of the burden of mentorship: recruiting students and conducting preinternship training workshops. In addition, mentor orientation sessions acquaint scientists with the educational background of incoming students and help them set realistic goals for the experience.

DEVELOPING THE OUTREACH CONTAGION

Although many scientists and institutions of higher education have had a long-standing interest in and relationships with precollege education, many are just now engaging in precollege education and outreach. The motivation for this is most likely due, in part, to the NSF mandate that funded projects outline the broader impacts of their research, including health benefits and public education. How do scientists engage in K–12 education efforts effectively and still meet their professional obligations for research, teaching, and service? Scientists are clearly concerned about how to balance the demands of research and undergraduate instruction with outreach and other educational activities. Graduate students and postdoctoral fellows involved in outreach must also consider this issue. Although there is significant concern that graduate students and postdocs engaged in outreach are spending less time at the bench, several research mentors who have students heavily involved in outreach have noted that these advisees have learned better time-management skills as a result of their outreach work (E. CALLAHAN, University of Wisconsin at Madison, personal communication). Also, students and postdocs have noted that outreach work reenergizes them and rekindles their excitement in bench science (TANNER *et al.* 2003). Most importantly, education is an integral part of what it means to be a scientist. Precollege education, outreach, and partnership can help both current and future scientists to develop mentoring and teaching skills.

Teachers often express interest in working with scientists, but are unsure about whom to contact at their neighboring university or research institute. The reverse situation is true just as often. Scientists who are parents of school-age children may find and exploit opportunities and contacts made in their children's schools (see Table 3). However, for scientists who lack these informal contacts, finding a partner teacher or school can be daunting. Some school districts may have a specific resource or contact person, but often they do not have the financial or human resources to support such a position. Many universities or research institutions have responded by creating science education, partnership, or outreach positions (see Table 2). Outreach personnel coordinate K–12 education and outreach activities while serving as points of contact for university colleagues and K–12 teachers. Outreach personnel can also play an integral role in bridging the cultures of science and education. Similarly, faculty in departments of science education can function as liaisons to local schools and as rich resources for the theory and practice of precollege education. Scientists and teachers alike are urged to seek out these professionals in their communities and to take advantage of their experience and expertise.

NSF strongly encourages education programs to disseminate their materials nationally, yet each geographic area has its own needs and resources (*e.g.*, urban *vs.* suburban *vs.* rural; Northeast *vs.* Southeast *vs.* Midwest *vs.* West). Cross-institution collaboration can support local implementation of distantly developed programs. By providing local support for dissemination of equipment- or personnel-intensive content, including genomics and biotechnology, this strategy also helps to broadly disseminate and sustain existing programs. Scientists are encouraged to seek out projects of interest and contact program personnel about implementing a program locally or adapting it to meet local teacher, student, and scientist needs. A list of programs can be found in Table 1 and on the following websites: Access Excellence (http://www.accessexcellence.org), The Arabidopsis Information Resource (http://www.arabidopsis.org/servlets/Search?action=new_search&type=community), the Fralin Biotechnology Center at Virginia Tech (http://www.biotech.vt.edu/outreach/programs.html), and the National Association of Health Science Education Partnerships (http://128.2.42.173/profiles.html).

SUSTAINING THE EFFORT

Several issues that may hinder long-term support of outreach remain: lack of professional rewards for participation in outreach, lack of training in precollege education, and lack of avenues for communication between and among K–12 and research institutions. There are programs addressing these problems, and we can look to them for solutions.

At institutions where promotion and tenure are based largely on research performance and undergraduate instruction, there is an obvious conflict with devoting time and resources to K–12 education. Yet, a few institutions formally evaluate faculty outreach efforts for consideration in promotion and tenure. For example, the Science Education Promotion and Tenure Committee in the University of Arizona's College of Science (http://samec.lpl.arizona.edu/aboutus/septc.html) evaluates faculty outreach and precollege education activities for consideration in tenure and promotion decisions. This approach not only rewards scholarly efforts in university-based K–12 education, but also encourages a high standard for participation in outreach. Given the many approaches outlined above, each of which entails a different level of commitment, scientists can engage in outreach to the extent that their institutions allow and require such activities.

A cadre of scientists skilled in interdisciplinary communication and pedagogy is needed (National Research Council 2002). A number of projects have been initiated to provide such training, including two NSF-sponsored programs: Graduate Teaching Fellowships in K–12 Education and Centers for Learning and Teaching. As more organizations become motivated to institute outreach programs, the need for trained personnel will increase. Professional ranking and reward equivalent to those available to research scientist peers will facilitate recruitment and retention of high-quality professionals in these positions (National Research Council 2002).

Engaging trained personnel whose primary responsibility is precollege education and outreach will likely enhance and speed the development of quality outreach programs. However, significant barriers to communication between research institutions and K–12 schools remain. To address this issue, the Science and Health Education Partnership at the University of California at San Francisco (http://www.ucsf.edu/sep) has developed a Partnership Workshop for teachers and scientists. The workshop introduces scientists to educational theory and practice, teachers to scientific inquiry and the nature of science, and both groups to each other's culture. For example, scientists typically have access to resources unavailable to teachers and possess a specialized knowledge base instead of the broad knowledge base of most educators. Also, scientists are taught to provide critical feedback to improve experiments, whereas teachers are encouraged to use positive reinforcement as a mechanism to help students improve. In addition, there is an entirely profession-specific context to much commonly used vocabulary (*e.g.*, matrix, inquiry, etc.). The workshop addresses these cultural similarities and differences explicitly, thereby reducing friction and confusion that may result as partnerships develop.

Scientists know the importance of professional meetings and journal publications for exchanging ideas with colleagues, learning new information, and establishing research collaborations. Professional societies, including the Society for Neuroscience, the American Society of Plant Biologists, the American Society for Cell Biology (ASCB), and others, are already including precollege education and outreach sessions in their annual meetings. National meetings or conferences that bring together scientists, outreach personnel, university-based science educators, and precollege teachers across disciplines encourage information exchange, development of collaborations, and dissemination of materials for science education. For example, North Carolina State University's Science House and the Burroughs-Wellcome Fund hosts a meeting on university-based K–12 science education (http://www.science-house.org/conf). More recently, professional journals, such as this journal, have begun to include manuscripts devoted to education along with research articles. The ASCB publishes *Cell Biology Education*, a journal devoted entirely to publication of high quality science education articles. Thus, professional societies can support and encourage participation of their membership in education by providing forums for information exchange and dissemination.

CONCLUSION

Adding precollege education and outreach to a scientist's research, teaching, and service responsibilities may seem overwhelming to both inexperienced and experienced faculty. In addition to the more intangible rewards of outreach such as improved teaching and communication skills, more concrete professional rewards are being offered, such as grant monies as well as weight in promotion and tenure decisions. Existing resources and expertise can help interested scientists avoid reinventing the wheel.

We thank the scientists, teachers, and outreach personnel who shared their invaluable insights so that we all may benefit from their lessons learned. This project was supported in part by a supplement to a National Science Foundation grant (DBI-9978564) and by the University of California Department of Agriculture and Natural Resources Biotechnology Workgroup. This is Carnegie publication no. 1625.

LITERATURE CITED

American Association for the Advancement of Science, 1990 *Project 2061: Science for All Americans.* Oxford University Press, New York.

American Association for the Advancement of Science, 1993 *Project 2061: Benchmarks for Science Literacy.* Oxford University Press, New York.

Bransford, J. D., A. L. Brown and R. R. Cocking, 1999 *How People Learn: Brain, Mind, Experience, and School.* National Academy Press, Washington, DC.

Jenkins, D. B., 2002 Why do some partnerships endure with individual professionals?, pp. 63–78 in *Effective Educational Partnerships: Experts, Advocates, and Scouts*, edited by S. Mitchell. Praeger, New York.

Lachtermacher, M., and P. J. Hines, 2002 Science Controversies: Online Partnerships in Education (SCOPE). Poster presented at the Conference on Communicating the Future: Best Practices for Communication of Science and Technology to the Public. Gaithersburg, MD.

Lederberg, J., and A. T. McCray, 2001 'Ome Sweet 'Omics—genealogical treasury of words. Scientist **15:** 8–10.

Loucks-Horsley, S., P. W. Hewson, N. Love, and K. E. Stiles, 1998 *Designing Professional Development for Teachers of Science and Mathematics.* Corwin Press, Thousand Oaks, CA.

National Research Council, 1996a *National Science Education Standards.* National Academy Press, Washington, DC.

National Research Council, 1996b *The Role of Scientists in the Professional Development of Science Teachers.* National Academy Press, Washington, DC.

National Research Council, 2002 *Attracting Ph.D.s to K-12 Education: A Demonstration Program for Science, Mathematics, and Technology.* National Academy Press, Washington, DC.

Tanner, K. D., and D. Allen, 2002 Approaches to cell biology teaching: a primer on standards. Cell Biol. Educ. **1:** 95–100.

Tanner, K. D., L. Chatman and D. Allen, 2003 Approaches to biology teaching and learning: science teaching and learning across the school-university divide—cultivating conversations through scientist-teacher partnerships. Cell Biol. Educ. **2:** 195–201.

Wormstead, S. J., 1999 *Designing Training Materials for Student-Teacher-Scientist Partnerships: A Guide for Scientists* (http://www.globe.unh.edu/STS.pdf).

Communicating editor: P. Pukkila