

## COMMENTARY

# Sowing the Seeds of Dialogue: Public Engagement through Plant Science

With enhanced public accessibility of scientific information, increased demand for a scientifically literate workforce and citizenry, stipulations from funding agencies to broaden the impact of science research, and changing rewards systems at universities, scientists are looking for ways to engage the public in their work. This commentary is designed to share our philosophy of engaging the public through partnership with the K-12 community and the strategies we learned along the way. We intersperse examples from efforts across the country and describe the story behind our own program as concrete examples of these strategies in action.

## A PLACE FOR PLANT SCIENCE IN K-12 EDUCATION

Over the past several decades, rapid advances in the life sciences, spurred by the emerging fields of genomics and information technology, have filtered into almost every arena of consumer goods and services, from food production to healthcare. As molecules, cells, and organisms become easier to manipulate and produce, individuals increasingly need to make choices about whether and how they use these products of life science. Equally important is the training of a future workforce. As of 2004, there were more than 40,000 bioscience organizations in the U.S. and Puerto Rico, employing 1.2 million people making an annual average wage of \$65,775, which is \$26,000 more than the average annual wage in the private sector (Biotechnology Industry Organization, <http://bio.org/speeches/pubs/er/statistics.asp>, accessed on 5/23/07). The demands of our changing economy and workplace require a workforce with a deeper understanding of biotechnology and scientific research.

The public also needs opportunities to better understand and critically evaluate the

issues that arise as a result of new developments in agriculture, medicine, and environmental science (Priest, 2000). Similarly, scientists need opportunities to communicate the importance of their findings to nontechnical audiences. These needs are compounded by the fact that only a fraction of high school graduates in the U.S. attend college (45% enroll), and an even smaller fraction major in the life sciences (3.5% of bachelor's degrees are conferred in the life sciences; Snyder et al., 2006). In fact, the last biology class most U.S. citizens take is in high school. These courses have higher enrollment rates than any other science disciplines, with 93% of high school graduates having taken at least one year of biology (Roey et al., 2001). Thus, the high school biology classroom is perhaps the last and most systemic opportunity for formal dialogue between scientists and the public about life science and its applications and implications.

The plant sciences present a uniquely flexible, scaleable, and compelling context for active investigation across the K-12 spectrum, including learning about the processes and nature of science. Plants are large enough to be manipulated by small hands, inexpensive enough to grow in the scale required in K-12 classrooms, and hardy enough for student caretakers. Although bacteria and yeast are easy to maintain and manipulate, safe and sterile preparation, storage, and disposal of microbial growth media can be problematic and cost-prohibitive for many classrooms. Likewise, investigations of animals present a host of concerns, including the logistics and cost of care and district regulations regarding animal experimentation. Despite the unique advantages of using plants as instructional tools, the plant sciences are underrepresented in K-12 curricula and textbooks (Wandersee and Schussler, 2001; Hershey, 2002; D.R. Hershey, <http://www.actionbioscience.org/education/hershey2.html#Primer>, accessed on 5/23/07).

Plant science also presents an almost untapped opportunity to engage the public in understanding the applications and implications of genomics, in particular, the development of genomic knowledge and its translation into products and practices. The results of genomic studies in microbes, plants, and animals, including humans, will have direct effects on the lives of today's high school students. The National Plant Genome Initiative has followed closely on the heels of the Human Genome Project, spurring the formation of genome-focused grant programs through the National Science Foundation (NSF) and the USDA. Complementary programs in other countries (e.g., the Arabidopsis Functional Genomics Network in Germany), as well as international plant genomics collaborations (e.g., projects funded by the NSF's Developing Country Collaborations in Plant Genome Research Program), are fodder for teaching students about the collaborative nature of science (American Association for the Advancement of Science, 1989; National Research Council, 1996a, 2000). Plant scientists, because of the classroom friendliness of their organisms of study, are uniquely positioned to engage K-12 learners and their teachers in this revolution.

Plants provide an excellent context for learning about the dynamic nature of genomes, especially the power of differential regulation of gene expression, a concept that is entirely new to most high school students. Animals can move to find food or mates and avoid harsh conditions or predators. Bacteria and other single-celled organisms have smaller genomes and reproduce more quickly, responding to their environments through rapid and abundant reproduction and genome reorganization. Plants respond to environmental and developmental cues through changes in metabolism and physiology that are dictated largely through changes in gene expression. Many students believe that genes alone define traits, rather than interacting

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with the environment to do so. The commonly cited examples of the genetic basis for eye and hair color in humans, as well as the classic wrinkled peas of Mendel, do nothing to challenge the conception that genes only influence appearance, not an organism's ability to respond to its environment. As a result, students have little opportunity to learn how environment and behavior shape the development of traits, from physical appearance to physiological response. Educational resources and collaborations developed in conjunction with plant genomics research are uniquely positioned to address this misconception.

A number of projects and an array of educational materials have been developed to teach about plant science (Table 1), but curricula aren't enough (Hershey, 1989, 2002; Wandersee and Schussler, 2001; D.R. Hershey, <http://www.actionbioscience.org/education/hershey2.html#Primer>, accessed on 5/23/07). Alan Leshner, CEO of the American Association for the Advancement of Science and executive publisher of *Science*, states in his recent editorial (2007):

...scientists must engage more fully with the public about scientific issues and concerns that society has about them...the notion of public engagement goes beyond public education. We must have a genuine dialogue with our fellow citizens about how we can approach their concerns and what specific scientific findings mean.

Wandersee and Schussler (2001) propose that plant mentors who provide knowledgeable and friendly experiences for children can help make research visible, accessible, and significant. Teachers can be invaluable partners in facilitating dialogue with our fellow citizens (i.e., students), as they have a working knowledge of students' knowledge and abilities, as well as pedagogical expertise and experience communicating with the public. Collaborations with teachers also ensure that any single effort has the potential to impact an exponential number of students. For example, plant scientist Anne Sylvester, in collaboration with scientists and educators from the University of Wyoming and surrounding schools, developed the Science Teacher Education Program (STEP) translational research experience for preservice

secondary science teachers. STEP partners teachers in training with science graduate students to provide them with hands-on science research experience and with experienced teachers to develop lessons related to their bench work. Through this type of mutually beneficial partnership, teachers and scientists are ideally positioned to enhance science learning through ongoing dialogue. Here, we describe how to initiate such a collaboration, noting the questions that guided our thinking (Table 2) and citing illustrative examples throughout, including our Partnership for Research and Education in Plants (PREP).

### PATHWAYS TO ENGAGEMENT: FROM MOTIVATION TO DISSEMINATION

We have described several major motivations for plant scientists and K-12 communities to collaborate, yet individuals get involved for reasons that are distinctly compelling to them, for example, when they volunteer in their own children's classrooms. Other opportunities arise more or less formally, for example, through conversations on the front porch with neighbors or across cups of coffee at a local meeting of Café Scientifique (<http://www.cafescientifique.org>). The critical element that not only instigates these efforts, but also ensures they are valued and sustainable them over time, is shared investment with the potential for mutual benefit (Figure 1).

### Needs and Resources in the Plant Science Community

In looking for ways to work with K-12 students and teachers, it is important to consider one's own interests, resources, and constraints. Do you enjoy working with young children? Are your own children of school age and would you like to offer their classmates a glimpse into the life of a scientist? Do you want to play a role in preparing students for undergraduate coursework? Do you want to develop insights into the skills, abilities, needs, and interests students have when they enroll in the classes you teach? Do you prefer working with adult learners, for example, teachers who can

then impact their students' learning year after year? Is your academic year already filled to the brim such that hosting a teacher or a more mature student for a summer lab internship is a better option than school year activities? Answering these questions is the first step in choosing which of the myriad ways you might collaborate with K-12 teachers and their students.

Next, it is important to consider the scientific content of your efforts and ways in which you might serve as a conduit for information and for ways of thinking about a discipline, thus providing a unique avenue for students and teachers to gain access to current scientific ideas, tools, and supplies. A wealth of biological and information resources are being generated through plant genomics efforts, from libraries of strains with inactivated genes to entire genome sequences. Using these resources for education increases public awareness of the scientific endeavor while enhancing "bang for the buck" (i.e., using the same materials for two purposes). For example, Plants-in-Motion developed by plant biologist Roger Hangarter and colleagues at Indiana University and the sLowLife exhibition Hangarter developed with artist Dennis DeHart at Buffalo State University of New York make available scientific images and videos and the tools used to generate them. In addition to highlighting concepts and skills related to plant science, one can model the processes of doing science and comment on its social, empirical, and dynamic nature (American Association for the Advancement of Science, 1989; National Research Council, 1996a, 2000).

### Needs and Resources in the K-12 Community

It is equally important to consider what the K-12 community needs and wants to know and what they have to offer. Start by listening carefully to teachers, students, and school administrators (e.g., Dolan et al., 2004; Elgin et al., 2005; Tomanek, 2005). What do they want to gain? What are the challenges they face? What types of skills and expertise can they share? What suggestions do they have about how best to meet their needs? For example, in response to requests from local

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**Table 1.** Example Resources for K-12 Plant Science Education

Curricular or Project Resources		Website
Elementary	Junior Master Gardener	<a href="http://www.jmgkids.us">http://www.jmgkids.us</a>
Secondary	New Plants Module	<a href="http://www.fossweb.com/modulesK-2/NewPlants/index.html">http://www.fossweb.com/modulesK-2/NewPlants/index.html</a>
	<i>Brassica</i> Genetics for the Classroom	<a href="http://www2.biochem.wisc.edu/brassicaclassroomgenetics/index.html">http://www2.biochem.wisc.edu/brassicaclassroomgenetics/index.html</a>
K-12	Grounding in Botany	<a href="http://www.huntington.org/Education/gib.html">http://www.huntington.org/Education/gib.html</a>
	Partnership for Research and Education in Plants	<a href="http://www.prep.biotech.vt.edu">http://www.prep.biotech.vt.edu</a>
	Virtual Plant Biotechnology and Genomics Laboratory	<a href="http://ppge.ucdavis.edu/Software/software.cfm">http://ppge.ucdavis.edu/Software/software.cfm</a>
	C-Fern	<a href="http://cfem.bio.utk.edu">http://cfem.bio.utk.edu</a>
	Fast Plants	<a href="http://www.fastplants.org">http://www.fastplants.org</a>
General Public	Plant Genome Research Outreach Portal	<a href="http://www.plantgdb.org/PGROP/pgrop.php">http://www.plantgdb.org/PGROP/pgrop.php</a>
	PlantingScience	<a href="http://www.plantingscience.org">http://www.plantingscience.org</a>
	Plants-in-Motion	<a href="http://plantsinmotion.bio.indiana.edu">http://plantsinmotion.bio.indiana.edu</a>
sLowLife Exhibition		<a href="http://plantsinmotion.bio.indiana.edu/usb">http://plantsinmotion.bio.indiana.edu/usb</a>
Other Useful Programs and Documents		
How People Learn: Brain, Mind, Experience, and School		<a href="http://www.nap.edu/html/howpeople1">http://www.nap.edu/html/howpeople1</a> (Bransford et al., 1999)
How Students Learn: History, Math, and Science in the Classroom		<a href="http://www.nap.edu/catalog/10126.html">http://www.nap.edu/catalog/10126.html</a> (Donovan and Bransford, 2005)
Inquiry and the National Science Education Standards		<a href="http://www.nap.edu/books/0309064767/html">http://www.nap.edu/books/0309064767/html</a> (National Research Council, 2000)
Project 2061, American Association for the Advancement of Science		<a href="http://www.project2061.org">http://www.project2061.org</a>
The Role of Scientists in the Professional Development of Science Teachers		<a href="http://www.nap.edu/catalog/2310.html">http://www.nap.edu/catalog/2310.html</a> (National Research Council, 1996b)
Funding Sources		
Howard Hughes Medical Institute	National Center for Research Resources	<a href="http://www.hhmi.org/research/professors">http://www.hhmi.org/research/professors</a> ; <a href="http://www.hhmi.org/resources">http://www.hhmi.org/resources</a>
National Institutes of Health (R25) Science Education Partnership Award		<a href="http://grants.nih.gov/grants/guide/pa-files/PAR-06-549.html">http://grants.nih.gov/grants/guide/pa-files/PAR-06-549.html</a> ; <a href="http://www.ncrrsepa.org">http://www.ncrrsepa.org</a>
National Science Foundation	National Institute on Alcohol Abuse and Alcoholism	<a href="http://grants2.nih.gov/grants/guide/pa-files/PAR-07-001.html">http://grants2.nih.gov/grants/guide/pa-files/PAR-07-001.html</a>
	National Institute on Drug Abuse	<a href="http://grants2.nih.gov/grants/guide/pa-files/PAR-06-518.html">http://grants2.nih.gov/grants/guide/pa-files/PAR-06-518.html</a>
	2010 Project	<a href="http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5337">http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5337</a>
	Broader Impacts Criterion	<a href="http://www.nsf.gov/pubs/gpg/broaderimpacts.pdf">http://www.nsf.gov/pubs/gpg/broaderimpacts.pdf</a>
	Division of Elementary, Secondary, and Informal Education	<a href="http://www.nsf.gov/od/lpa/news/publicat/nsf04009/ehr/esie.htm">http://www.nsf.gov/od/lpa/news/publicat/nsf04009/ehr/esie.htm</a>
The Wellcome Trust	Division of Research, Evaluation, and Communication	<a href="http://www.nsf.gov/od/lpa/news/publicat/nsf04009/ehr/rec.htm">http://www.nsf.gov/od/lpa/news/publicat/nsf04009/ehr/rec.htm</a>
	Graduate Teaching Fellows in K-12 Education	<a href="http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5472">http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5472</a>
	Math and Science Partnership	<a href="http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5756">http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5756</a>
	Plant Genome Research Program	<a href="http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5338">http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5338</a>
		<a href="http://www.wellcome.ac.uk/funding/publicengagement">http://www.wellcome.ac.uk/funding/publicengagement</a>
Professional Organizations		
American Society for Cell Biology		<a href="http://www.ascb.org/index.cfm?navid=6">http://www.ascb.org/index.cfm?navid=6</a> ; <a href="http://www.lifescied.org">http://www.lifescied.org</a>
American Society of Plant Biologists		<a href="http://www.aspb.org/education">http://www.aspb.org/education</a>
Association for Science Teacher Education		<a href="http://aste.chem.pitt.edu">http://aste.chem.pitt.edu</a>
Botanical Society of America		<a href="http://www.botany.org/outreach">http://www.botany.org/outreach</a>
National Association of Biology Teachers		<a href="http://www.nabt.org">http://www.nabt.org</a>
National Association for Research in Science Teaching		<a href="http://www.narst.org">http://www.narst.org</a>
National Science Teachers Association		<a href="http://www.nsta.org">http://www.nsta.org</a>
The Arabidopsis Information Resource		<a href="http://www.arabidopsis.org/portals/education">http://www.arabidopsis.org/portals/education</a>

high school students and teachers, plant scientists Doug Cook and David Gilchrist and education coordinator Barbara Soos from the Partnership for Plant Genomics Education at the University of California at Davis are developing the Virtual Plant Biotechnology and Genomics Laboratory. Through up-to-date articles, animations, and videos, this software will illustrate the processes of generating DNA libraries, clon-

ing genes, transforming plants, selecting transformants, and generating and maintaining transgenic lines as well as the genetic and genomic principles behind gene expression, RNA interference, and responses to abiotic stresses. Although some would argue that virtual experiences pale in comparison to hands-on activity, many genetics and genomics investigations are not appropriate for precollege students for safety rea-

sons or because of geographic distance and cost. Because the virtual laboratory will be available on CD-ROM and through the Internet, it will be available to local schools that may not have resources or time for field trips to the university as well as to more geographically distant audiences.

There are strong rationales for working with students of all ages, not only to enhance their learning experiences but

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**Table 2.** Summary of Recommendations with Examples from PREP

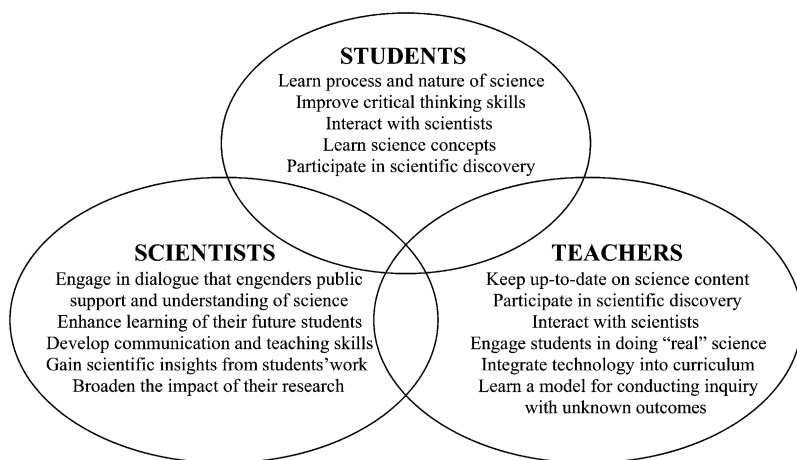
Recommendations	PREP Examples
Evaluate your needs, interests, and resources as well as those of the K-12 community you wish to engage.	<ul style="list-style-type: none"> <li>● Students and teachers wanted opportunities to collect real data of interest to the scientific community.</li> <li>● Scientists wanted help characterizing the functions of genes in <i>Arabidopsis</i>.</li> <li>● PREP content, as well as the manual dexterity required for growing, observing, and experimenting with <i>Arabidopsis</i>, are most appropriate for high school.</li> </ul>
Identify existing curricula, programs, and personnel that can support your efforts.	<ul style="list-style-type: none"> <li>● Scientists and teachers serve as advisors in ongoing development of the program.</li> <li>● An experienced teacher wrote the guidelines for classroom implementation.</li> <li>● The project coordinator has been both a classroom teacher and <i>Arabidopsis</i> researcher.</li> </ul>
Develop a specific plan involving a finite commitment and clear expectations.	<ul style="list-style-type: none"> <li>● PREP partners teachers and plant scientists in guiding high school students in designing and conducting their own original investigations to determine how disabling a gene in <i>Arabidopsis</i> affects the plant's ability to respond to environmental stresses.</li> <li>● PREP is a mutual learning effort in which scientists gain pedagogical skills and insights as well as potentially informative results from students' work, and students and teachers learn about the culture, content, and process of science.</li> </ul>
Develop a strategy to document the impact of your efforts, collaborating with education researchers and evaluators as possible.	<ul style="list-style-type: none"> <li>● An external evaluator and graduate students in education research collaborate with PREP personnel and education research faculty to investigate the practice and impacts of PREP.</li> <li>● Data are gathered from a variety of sources, including classroom observations, student work, and interviews or focus groups with students, teachers, and scientists.</li> </ul>
Speak publicly and often to contribute to a change in culture that supports public engagement within the scientific community.	<ul style="list-style-type: none"> <li>● Program information, outcomes, and impacts are shared with practicing teachers through state and national teacher meetings and with the education and science research communities through national meetings and publications.</li> <li>● Letters of support are written for scientists who broaden the impact of their research through PREP participation.</li> <li>● Virginia Tech's Biochemistry Department now offers outreach assistantships in addition to teaching assistantships for interested doctoral students.</li> <li>● University of Arizona and Virginia Tech have changed their promotion and tenure guidelines to include an expectation of and reward for public engagement.</li> </ul>

also to recruit future scientists. For example, when compared with time spent on science, nearly four times as much is spent on reading and language arts and twice as much on mathematics in the early elementary grades, with only a slight evening of the ratio in late elementary grades (Gruber et al., 2002). This may be the result of an emphasis on standardized testing in reading, writing, and mathematics, teachers' lack of interest in, enthusiasm about, or preparation to teach science, or uncer-

tainty about their science teaching abilities (Manning et al., 1982; Stevens and Wenner, 1996; S.K. Abell and M. Roth, Coping with constraints of teaching elementary science: A case study of a science enthusiast student teacher, Annual Meeting of the National Association for Research in Science Teaching, Lake Geneva, WI, April 7–10, 1991). In middle school, equal time is dedicated to each of the subjects, yet teachers are often teaching out of their discipline because of shortages of qualified

individuals (Seastrom et al., 2004). Students' interest in science also wanes at this age (Simpson and Oliver, 1990; Greenfield, 1996; Jovanovic and King, 1998). A significant fraction of high school teachers also teach out-of-field, which has a demonstrated impact on student achievement (Darling-Hammond and Hudson, 1990; Monk, 1994; Goldhaber and Brewer, 1997; Ingersoll, 1999); only 60% of biology students at the secondary level in 1999 to 2000 were taught by teachers with a major

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**Figure 1.** The Benefits of Participating in PREP Are Mutual.

Through evaluation and study of PREP, we have identified the benefits of participating in PREP.

or minor in biology (Seastrom et al., 2004). High school laboratory learning experiences, which are correlated with positive attitudes toward science and increased science achievement, are not available to all students (Freedman, 1997; National Research Council, 2006). When lab learning is available, often it is not integrated into the flow of instruction and does not include time or opportunities for students to reflect on or discuss their work. In addition, the majority of laboratory activities are demonstrations with predictable outcomes. These activities can play a useful role in illustrating concepts or helping students learn techniques. Yet, if demonstration labs are the only laboratory instruction tools in use, students miss an opportunity to experience the excitement of discovery and learn that science is about generating new knowledge.

K-12 students and teachers have much to offer to the scientific community. Children and their teachers bring creative, original, and big picture ways of thinking about science because they are not steeped in it on a daily basis and they have not yet narrowed their interests or expertise. Youthful exuberance and enthusiasm about using the tools and materials of science can be contagious, often rekindling scientists' interest in their own work (K.D. Tanner, Evaluation of scientist-

teacher partnerships: Benefits to scientist participants, National Association for Research in Science Teaching Annual Conference, New Orleans, LA, April 30–May 3, 2000; A. Busch and K.D. Tanner, Developing scientist educators: Analysis of integrating K-12 pedagogy and partnership experiences into graduate science training, National Association for Research in Science Teaching Annual Conference, San Francisco, CA, April 3–6, 2006). Classrooms are filled with groups of budding scientists and future scientifically literate citizens who can collaborate with scientists across time and distance using synchronous and asynchronous tools, such as e-mail or virtual meeting software (e.g., Adobe Breeze). Finally, a growing body of evidence demonstrates that scientists benefit from collaborations with K-12 students and teachers. Scientists learn new teaching skills (e.g., S.A. Spillane, Sharing strengths: Educational partnerships that make a difference, Annual Meeting of the American Educational Research Association, San Diego, CA, April 12–16, 2004) shape their own teaching based on knowledge and practice generated through K-12 education reform (e.g., J.M. Bower, <http://www.nas.edu/rise/backg2a.htm>, accessed on 5/11/07), expand their awareness and understanding of the opportunities and challenges in precollege education (e.g.,

McKeown, 2003; J.M. Bower, <http://www.nas.edu/rise/backg2a.htm>, accessed on 5/11/07; T. Schultz, <http://nas.edu/rise/backg2d.htm>, accessed on 5/11/07), and grow in their own identities as scientists and educators (A. Busch and K.D. Tanner, Developing scientist educators: Analysis of integrating K-12 pedagogy and partnership experiences into graduate science training, National Association for Research in Science Teaching Annual Conference, San Francisco, CA, April 3–6, 2006).

### Collaboration

Once you have initiated a conversation with a teacher or school administrator and discussed how best to match your needs and resources to a mutually beneficial end, what do you actually do? First, take advantage of existing resources. The development of high-quality curriculum is time-consuming and expensive, requiring significant breadth and depth of expertise in teaching, learning, educational research, and science knowledge. A wealth of tried and true plant science curricula have been developed that span the K-12 curriculum (Table 1). Some can be used to illustrate ecosystem and organism level concepts, such as gardening programs like Junior Master Gardener or the kit- and Web-based New Plants Module from Full Option Science System. Others are intended to demonstrate molecular concepts, such as *Brassica* Genetics for the Classroom, developed by plant biologist Rick Amasino at the University of Wisconsin. Yet others can be used to teach biological concepts and processes that span a number of grade levels, such as C-Fern, developed by plant biologists Leslie Hickock and Thomas Warne at the University of Tennessee at Knoxville, and Fast Plants, developed by plant biologist Paul Williams at the University of Wisconsin. Although these materials may not directly fit the learning objectives you have in mind, you and your school colleagues can alter them to fit your needs. For the most part, teachers are interested in identifying anything that helps their students learn. Teachers will eagerly adopt learning materials that address a gap in their existing curriculum or improve on the

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curriculum already in use, especially if the materials are low cost, scaleable (in some states, high school teachers have 175 students or more), and flexible (easily integrated into existing curriculum; e.g., Evans et al., 2001; Elgin et al., 2005).

Consider joining an existing project with an established network of participating schools so that you can spend your time working with students and teachers rather than designing and administering a program. For example, the Botanical Society of America has capitalized on Wandersee and Schussler's idea of plant mentorship by establishing an online plant science mentorship program, PlantingScience. In this program, students can design and conduct hands-on investigations with in-class guidance from their teachers and Web-mediated mentorship from plant scientists. A number of institutions, especially land grant universities with well-developed outreach and extension programming, have either physical or virtual clearinghouses of projects and resources for working with K-12 schools, for example, University of Arizona's Science and Mathematics Education Center and Virginia Tech's K-12 Science, Technology, Engineering, and Mathematics Education Outreach Initiative. These sites serve as portals to resources, projects, and personnel with special interest and expertise in working with K-12 audiences. Professional societies (e.g., the American Society of Plant Biologists, etc.) and grants-making organizations (e.g., the NSF, the National Institutes of Health, the Howard Hughes Medical Institute [HHMI], etc.) often make their K-12 education resources available through their own websites or the sites of grantees. For example, the NSF's Plant Genome Research Program has supported the development of K-12 plant science education resources and the Plant Genome Research Outreach Portal that makes these resources accessible.

Most importantly, make a finite commitment with defined expectations (Moreno, 2005). Keep in mind that many of the constraints K-12 students and teachers experience in their classrooms are magnified versions of those we experience in teaching our own courses (McKeown,

2003). Budgets are limited, time is tight, space is inadequate, and there is too much content to cover. Teachers have the added challenges of addressing standards mandated at the national, state, district, and even school levels, being held responsible for this work based on their students' test scores even to the point of being paid based on student achievement. Teachers have little to no time during the day to plan lessons, prepare lab materials, grade student work, respond to student and parent concerns, or even eat lunch; thus, much of the collaboration may need to occur after their school day has ended. Think through the logistics of your plan as well as how you will communicate about and alter the plan if and when contingencies arise. What do you plan to do? When will activities start and end? Whose responsibility is it to gather materials, lead instruction, and conduct the evaluation? Ultimately, as experienced teachers know, not everything can be planned or anticipated and you will have to just do it.

In our case, we started by identifying the needs and resources of high school biology students by regularly soliciting feedback from an advisory group of their teachers. During one such session several years ago, the group noted the absence of opportunities for students to collect real data. We then brainstormed about what real experiments could be done in a classroom, keeping in mind students' interests, district regulations, and required course content. We chose to focus on *Arabidopsis thaliana*, a member of the mustard family, because it offers two distinct advantages for investigation in high school classrooms: it is well characterized at the molecular level and it is the subject of study by more than 10,000 scientists around the world. Other benefits of using *Arabidopsis* in the classroom include many of the advantages that make it a good model for research: rapid life cycle, abundant progeny, and small size. Most importantly, the NSF has established a program, the 2010 Project, the objective of which is to determine the function of all genes in *Arabidopsis* by the year 2010 with the ultimate goal of developing a comprehensive understanding of the biology of flowering plants. Many of the scientists who have received funding from this pro-

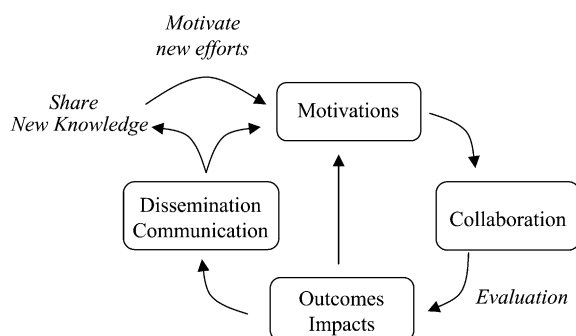
gram have disabled their genes of interest, grown the resulting mutant plants, and looked for any changes in the plant's growth and development, finding no apparent phenotypes (Cutler and McCourt, 2005).

While functional redundancy is likely at work, it is also likely that many genes are not expressed without the proper environmental signal, for example, heat, humidity, or pathogen infection. Plants have had 500 million years of evolution to adapt to every biome on Earth. The stationary nature of their existence would suggest that they have an arsenal of genes for responding to changes in their environment. Growing mutant plants under stress conditions allows for a more comprehensive analysis of gene function. This is the basis of PREP, which provides genuine research experiences to high school students and teachers, while helping scientists to discover the functions of poorly characterized plant genes. High school students design and conduct experiments on mutant lines of *Arabidopsis* under a variety of stress conditions and then analyze their phenotypes, reporting their findings to partner scientists. In the PREP blueprint for experiments, students compare wild-type and mutant plant growth in control versus experimental conditions. This common structure enables efficient and realistic mentorship by collaborating teachers and scientists. Guidelines are available through PREP's website for teachers and scientists to implement the collaboration locally. In addition, the password-protected portion of the site enables distant dialogues between classrooms and scientists through project-based blogs.

### Evaluation

Although it is not within the scope of this commentary to fully describe the methods and nuances of science education research and evaluation, it is essential to ask the question: How will you know that what you are doing works? Determine what evidence will convince you and your school colleagues that you are achieving your intended goals. A good first step is to discuss what data would be evidence that you are achieving your goals and how to go

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**Figure 2.** Putting the Pieces Together: The Cycle of Engagement.

Designing sustainable partnerships requires careful, ongoing consideration of the needs and resources of everyone involved. The plant science and K-12 communities each have their own motivations that spawn collaboration. The resulting outcomes and impacts, demonstrated through evaluation, serve as motivation to continue the collaboration and as findings and products that can be shared with new audiences, in turn motivating others to start their own collaborations.

about collecting and analyzing these data and reflecting on the results. Data can be collected more or less formally in a number of ways, including both qualitative and quantitative methodologies (Anfara et al., 2002; Frechtling and Westat, 2002; Sundberg, 2002; Ercikan and Roth 2006). If you are interested in interpreting the outcomes and impacts of your effort in a more systematic, rigorous, and generalizable way, consider collaborating with an education evaluator or researcher or a graduate student in education who is mentored by faculty with appropriate expertise and is seeking a dissertation project.

In collaboration with an external evaluator and with the involvement of doctoral students in education research, we have sought evidence of PREP's impact on the interests, attitudes, and learning of participating students, teachers, and scientists (e.g., Dolan, 2006; E.L. Dolan, J. Grady, and D. Lally, Defining authenticity within a student-teacher-scientist partnership, National Association for Research in Science Teaching Annual Conference, New Orleans, LA, April 15–18, 2007). To date, PREP has engaged more than 8400 students representing diverse ethnic, economic, and geographic backgrounds and enrolled in life science and agriculture classes across grades 9 to 12, including special education, standard, honors, advanced, and English language learners. Twenty scientists have

participated in one or more of these ways: provided seeds, made classroom visits, communicated with students via e-mail or video chats, provided experimental advice, and collaborated with teachers in developing techniques or lessons. Several scientists are following up on students' findings with the intention of including their work in future publications (B. Winkel and J. Watkinson, personal communication).

### Dissemination and Communication

Different aspects of your work will likely be of interest to different audiences, including teachers, scientists, and education researchers. Most professional organizations have annual meetings, print or online peer-reviewed publications, and websites that enable individuals to reach their membership (Table 1). For example, many teachers attend annual meetings of state or national science education organizations, which comprise how-to workshop sessions and keynote speakers on current issues in science and education. Many scientific societies have venues where members share their educational innovations and resulting impacts online, in journals, or at meetings. Some science associations may have dedicated K-12 education sessions at their annual meetings or subsidize the participation of K-12 teachers in meeting events. Education researchers and evalua-

tors communicate through their own professional organizations, including general associations and those dedicated to science teaching and learning. These venues provide opportunities to get feedback from other scientists and educators about your work, share the lessons you have learned, disseminate the materials you have developed, and contribute to the body of knowledge about science teaching and learning (Figure 2).

Teachers have played a critical role in PREP's expansion. Even though the project spans 6 to 8 weeks, teachers are willing adopters because PREP was designed with substantial consideration given to the constraints facing high school classrooms ( $n = 61$  participating teachers by the end of the 2005–2006 academic year, 46 of whom have participated for multiple years). Its alignment with learning objectives seen in high school biology courses across the nation and its flexible structure enable teachers to choose which concepts and skills they would like to teach (American Association for the Advancement of Science, 1989; National Research Council, 1996a; Brooks et al., 2003). Teachers note that the primary benefit of participating is the uniquely authentic opportunity to teach their students about the processes of science (87%,  $n = 38$  respondents), including increasing their ability to design and conduct experiments, display data in a useful manner, use data to support or refute hypotheses, work in small groups, and share their findings with others. All of these considerations contribute to PREP's scalability, and it is currently being disseminated through partnerships among high schools and universities across the country.

### FINAL THOUGHTS

A supportive infrastructure is developing and a number of rewards are already available to those who heed Leshner's call for dialogue (Leshner, 2007). Some institutions have reward systems in place, including new promotion and tenure metrics, to encourage and compensate faculty who dedicate time and energy to engaging the public. For example, Virginia Tech recently revised its promotion and tenure policy to ensure

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that a faculty member's accomplishments in research, instruction, and outreach be acknowledged in accordance with his or her assignment. Although this change may not seem revolutionary, it gives departments permission to appoint faculty whose primary responsibility is public engagement and to evaluate them accordingly, rather than with respect to metrics more appropriate for faculty engaged in basic or applied research. The University of Arizona has established a Science Education Promotion and Tenure Committee to assist science departments in evaluating faculty whose primary appointment involves the preparation and professional development of science teachers.

Other institutions are dedicating significant resources to building the public engagement capacity of current and future science faculty. Many of these efforts have been initiated in response to challenges and expectations of extramural funding agencies. For example, the NSF will not consider any proposal for funding that doesn't explicitly address how the investigators will broaden the impact of their research through education, outreach, or mentorship. The Wellcome Trust has established Engaging Science, a grant program designed to support national and international efforts to engage the public in biomedical science, as well as better understand how this is accomplished. The HHMI professors program supports efforts to reform undergraduate teaching and learning for students majoring in science and other disciplines. Many of the individuals in HHMI's Society of Professors also engage precollege audiences through their undergraduate work or through complementary efforts. Thus, the "carrots" available to scientists interested in public engagement are multiplying. We anticipate that these efforts will eventually blur the line between the plant science and K-12 communities, laying the groundwork for problem solving and knowledge sharing across the K-20+ continuum of science learning. We hope this article challenges scientists to seek out teachers as partners, using their shared interest in and passion for science learning to initiate mutually beneficial collaborations.

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