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A Scientist's Guide to Achieving Broader Impacts through K–12 STEM Collaboration

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The National Science Foundation and other funding agencies are increasingly requiring broader impacts in grant applications to encourage US scientists to contribute to science education and society. Concurrently, national science education standards are using more inquiry-based learning (IBL) to increase students' capacity for abstract, conceptual thinking applicable to real-world problems. Scientists are particularly well suited to engage in broader impacts via science inquiry outreach, because scientific research is inherently an inquiry-based process. We provide a practical guide to help scientists overcome obstacles that inhibit their engagement in K–12 IBL outreach and to attain the accrued benefits. Strategies to overcome these challenges include scaling outreach projects to the time available, building collaborations in which scientists' research overlaps with curriculum, employing backward planning to target specific learning objectives, encouraging scientists to share their passion, as well as their expertise with students, and transforming institutional incentives to support scientists engaging in educational outreach.

Keywords: broader impacts, K–12 STEM education, inquiry-based learning, scientific literacy

There is a growing sentiment in the United States that in addition to conducting primary research, scientists should be more directly engaged in science education (NSF 1999, Alberts 2013). This paradigm shift is fueled by the concern that K–12 education is not adequately preparing students to become scientific leaders and the realization that solving complex twenty-first century problems will require a scientifically literate society (NRC 2007, Feinstein et al. 2013, Mervis 2013). The recent addition of the broader impacts requirement of the National Science Foundation (NSF) grant applications exemplifies this sentiment, challenging scientists to develop research and activities that benefit science, technology, engineering, and mathematics (STEM) education, the greater scientific community and society at large (NSF 2011). Although scientists may support the principles of this requirement, ambiguity in its criteria have left many feeling frustrated and unprepared to incorporate broader impacts into their programs without detracting from the quality of their research (Sarewitz 2011). However, given the right tools and guidance, there are many ways for scientists to successfully achieve broader impacts in concert with their research goals. One particularly promising avenue is enhanced involvement in K–12 STEM educational outreach, in which scientist participation has immense potential to positively affect the professional development of scientists, student achievement, and public scientific literacy (Nucci et al. 2011, Ufnar et al. 2012, Alberts 2013). The NSF's own Graduate K–12 (GK–12) Program has been highly successful in its original goals of enhancing graduate student professional development, as well as being the only NSF program that has truly embedded scientists in local communities, forging lasting partnerships (Boone and Marsteller 2011, AAAS 2013).

Concurrent with the shift in societal expectations of scientists are efforts to change science education to foster more creativity, diversity, and rationality, with the goal of developing abstract, conceptual thinkers who can tackle real-world problems (Anderson et al. 2011, Alberts 2013). Recent K–12 STEM education frameworks, including the *Next Generation Science Standards*, strongly emphasize inquiry-based learning (IBL) approaches (NRC 2000, 2012, Duschl et al. 2007). Inquiry-based learning is a dynamic approach through which students discover information and construct knowledge through experience. The continuous process of discovery is emphasized rather than memorization of facts (Gyllenpalm et al. 2009), fostering student scientific

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curiosity, critical thinking skills, and an understanding of how science works (NRC 2005). Educational outreach using IBL is particularly well aligned with many of the NSF's broader impacts criteria; it promotes student engagement with science, improves scientific literacy and intellectual independence in K–12 students, and has the potential to increase minority participation in STEM (Lynch et al. 2005, Hmelo-Silver et al. 2007, Moskal et al. 2007, Geier et al. 2008, Minner et al. 2010, Wilson et al. 2010). Likewise, scientists' expertise in scientific inquiry fits naturally with IBL educational outreach, fulfilling broader impacts requirements and benefiting STEM education.

Scientists also benefit from IBL collaborations through enrichment and diversification of skills crucial to their professional advancement. Beyond merely a donation of time and resources, educational outreach can be an investment in scientists' career development via a mutually beneficial collaboration. University science faculty and graduate students participating in K–12 outreach more effectively communicate their science within and beyond the scientific community, making their research more accessible to their peers, the public, and policymakers, and supporting stronger mentoring and collaborative relationships (Trautmann and Krasny 2006, Moskal et al. 2007, McBride et al. 2011). Engaging with K–12 students also requires scientists to think creatively and be highly adaptable (Williams 2002, DeHaan 2011), abilities that are fundamental to successful scientists. Although many academic scientists are concerned that outreach commitments will reduce productivity, particularly for their graduate students, NSF K–12 graduate fellows gained crucial time management skills and actually enhanced their research scope and achievements (Williams 2002, Trautmann and Krasny 2006, AAAS 2013). Additionally, K–12 outreach confers important benefits to academic institutions as a whole by strengthening educational partnerships and enhancing universities' relationships with their local communities (Williams 2002, AAAS 2013).

The convergence of new expectations of scientists and science education provides fertile grounds to foster beneficial scientist–educator partnerships. The NSF made an initial investment via their GK–12 program and demonstrated widespread benefits of these collaborations (AAAS 2013); it is now up to the scientific community to build on this foundation. Despite the many benefits of educational outreach as a broader impact, obstacles can inhibit or prevent scientists from having rewarding outreach experiences. Here, we identify common challenges coupled with creative solutions to support interested scientists in developing IBL-focused, K–12 educational partnerships as broader impact components of their research programs. We produced this practical guide on the basis of our experiences developing and participating in the NSF Graduate K–12 Education program, CAMEOS (for Coastal, Atmospheric, and Marine Environmental Observing Studies; *http://bml.ucdavis.edu/education/cameos*) at the University of California, Davis', Bodega Marine Laboratory. In this program, science graduate student fellows partner with K–12 educators, using IBL methods to guide students through the steps of scientific inquiry.

Adaptability, flexibility, and creativity are crucial threads woven into strategies for effectively coping with all the common challenges of educational outreach, skills that also underpin innovative research. Although the goals of achieving broader impact through IBL in science education are clear, most scientists are not trained in IBL educational outreach. Our practical guide illuminates one pathway to successful IBL educational outreach and highlights the benefits to scientists.

Strategies for successful K–12 IBL outreach

Despite the many benefits of IBL educational outreach, obstacles can prevent scientists from pursuing educational outreach or having rewarding educational outreach experiences. Here, we identify common challenges to implementing IBL outreach, coupled with creative and adaptable solutions to support scientists who endeavor to share their expertise and enthusiasm about science with K–12 students.

Challenge 1: Time constraints. *Scale to the time available*. A common major obstacle for scientists to overcome in K–12 IBL engagement is carving out sufficient time amid the research and institutional responsibilities dictated by their positions. The key to surmounting this hurdle is the strategic selection of an educational outreach project that fits the schedules and time constraints of the scientists (along with other circumstances of the project; table 1, figure 1). The time commitment could range from a few hours planning and a few more hours executing a single lesson to guiding students through scientific projects of their own over the course of many class periods spread throughout a school year (tables 2 and 3). The latter type of project is one for which scientists might seek funding and engage colleagues in larger collaborations (see the supplemental material). Adaptations such as afterschool clubs, camps, and other informal options may be better matches for scientists with strict time constraints during normal working hours (Petersen 2011). Investing a few hours to consult with experienced colleagues, school administrators, and potential educational collaborators about a potential IBL project will help scientists set feasible expectations and realistic time lines, ultimately saving them time, effort, and frustration. For example, CAMEOS scientists discussed their IBL project ideas as well as a list of logistical questions created by former participants with their collaborating teachers (box 1), addressing issues often unfamiliar to scientists such as required security and health risk prescreening (e.g., tuberculosis testing, fingerprinting, facility permissions), resource availability (e.g., computer hardware, software, and internet access required for projects such as online database searches) and logistical challenges of field trips or extracurricular events (e.g., offsite permission protocols, coordinating and funding transportation, and scheduling around examinations). As scientists gain experience in guiding students through IBL projects, they will be able to conduct more in-depth projects without increasing their time commitment.

Table 1. Influential factors. Discussing key factors influencing goals and activities with K–12 collaborators facilitates realistic, compatible expectations and project success.

Scientist and educational collaborators	K–12 students and school
Time availability	Grade level
Scientific discipline	Socioeconomic factors
Teaching experience	School and classroom culture
Available resources for outreach	Available school resources
	Technology knowledge and availability
	Curriculum standards

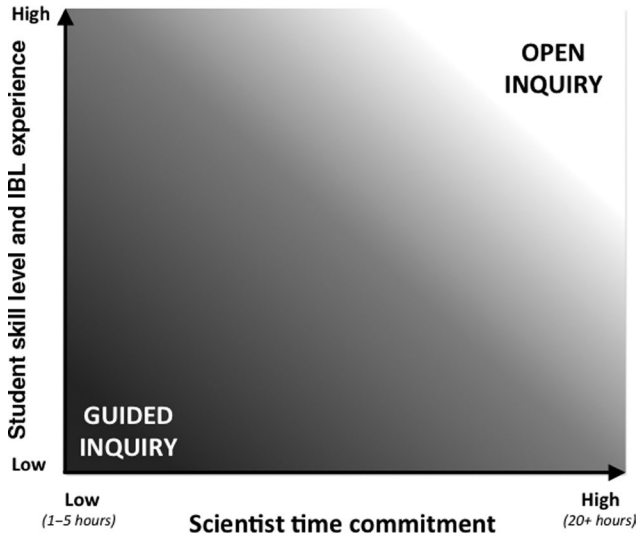

Figure 1. Conceptualizing guided-to-open inquiry as a continuum influenced by scientist time commitment and student skill level and experience helps scientists tailor inquiry-based learning (IBL) activities to best match their situation. Students with little or no IBL experience combined with time-limited scientists (less than 5 hours) falls into the guided inquiry realm. Scientists with more time can implement semiguided activities (approximately 6–10 hours) or lead students through a guided inquiry project that encompasses the complete scientific process (more than 20 hours). Scientists and more-advanced students can address more components of the scientific process in a guided inquiry, or allow the students to develop their own scientific questions even if the scientists' time commitment is lower. Higher student level and scientist time commitment provide the best combination for open inquiry in IBL activities, allowing students ownership of their projects and exposure to the entire scientific process.

Use technology to enrich the experience within time limitations. Many technological tools can help scientists creatively adapt educational outreach approaches to maximize their impact within their time constraints. For example, CAMEOS scientists used streaming video and photographs to create virtual field trips to their field sites to help students understand the environmental variables and experimental designs of their research, without needing to fund and coordinate excursions (tables 2 and 3). Researchers can share online data sets with students when time or logistics prevent students from collecting data themselves (Nucci et al. 2011; also see the supplemental material). With online cloud storage platforms and university or school Web sites, scientists can share documents with teachers, students, and scientific colleagues, allowing for collaborative lesson development, remote feedback on student projects, and shared science content when time constraints prevent in person meetings. However, scientists may need to be flexible and adapt activities to the accessible resources in their classroom. Technological infrastructure within K–12 schools can be very diverse, ranging from exceeding university-level access to completely inadequate. By including an assessment of available technological resources in planning discussions with educational partners, scientists can tailor their outreach to capitalize on the available resources (table 1). There are many online resources that can also assist scientists in using technology to enhance science education (supplemental material). In addition to saving time, these technological tools can showcase scientists' technical capability when applying for funding for IBL partnerships (Spalding et al. 2010) or stipends to support graduate students engaging in IBL outreach (Ufnar et al. 2012). Becoming more efficient in IBL educational outreach through the creative use of technology will minimize sacrifices in research activities.

Challenge 2: No experience collaborating with K–12 educators. *Find the right collaborator*. Scientists may be discouraged from exploring K–12 outreach because they are not connected with the appropriate networks to find educational collaborators (Petersen 2011). However, no matter where scientists are located, there are likely schools nearby with students who can benefit from interacting with scientists. Educational partnerships in which scientists' research overlaps with K–12 curriculum are particularly rewarding and embody the NSF's core aim to broaden the impact of scientists' own research. Reading curriculum standards can help scientists determine the subject and grade level that is best matched to their expertise (supplemental material). Scientists can identify local partners directly by reaching out to principals or teachers at local schools (CNCS 2013), inquiring at their own or colleagues' children's schools, finding connections through their institution's education department and existing outreach programs (e.g., at local museums), or consulting online resources (supplemental material). Coordinating with the university's education department is particularly advantageous for scientists, because it provides access to educational expertise, networks, and infrastructure and can enhance the credibility of scientist outreach programs within the K–12 educational community (Williams 2002).

Develop a partnership with open communication. Successful collaborations require a shared vision based on clear and mutually agreed upon goals and expectations, effective communication, and well-defined roles and responsibilities

Table 2. A logistical guide to the steps of mentoring K–12 students through open inquiry projects based on the NSF GK–12 CAMEOS program.

Objectives	Time	Possible activities and tips
Observe and brainstorm questions	1–6 hours	Students make observations through a virtual field trip. Bring photographs or other evidence into the classroom. Students make observations during a field trip. Provide students with prompts about what they might look for and a directive to record all questions and observations. Worksheets can provide structure and maintain focus.
Refine questions	2–4 hours	Define scientific questions and provide examples of questions that are scientific and those that are not. Show students how to rewrite questions to make them testable, and have them practice with their own questions. Provide feedback as students select research questions and discuss time, logistics, and supply limitations.
Develop hypotheses	0.5–3 hours	Ask students to make an educated guess about what they will find and prompt them to justify their hypotheses. With more time, guide them through background research to inform hypotheses. Provide guidance for reliable online information sources appropriate to student level.
Design research	2–4 hours	Present examples of how scientists conduct experiments. Use fictional or real-world examples to help students identify the value of replication. Ask students to brainstorm research methods and present them to gain feedback. Prompt students to identify required materials and how they will obtain each of these supplies.
Collect data	2–8 hours	Students collect data within a designated number of class periods or field trip with guidance from the scientist. More experienced students collect data independently on their own time and consult with the scientist as needed.
Analyze data graphically	3–5 hours	If learning to use data management software is a focal skill, expose students to software in a guided activity prior to analyzing their own data. Mastery of analysis tools can more than double the time investment in this step and should be supported with lessons and learning tools. Students can alternatively calculate simple statistics and graph data by hand.
Draw conclusions	1–5 hours	Ask students to think about implications of results, beyond quickly declaring hypothesis support or falsification. Facilitate broader thinking via group brainstorms or homework assignments of prompted discussion topics.
Communicate science	2–12 hours	Students can create hand-drawn posters to present to their classmates in a research forum in a shorter time frame. Students can compose a slideshow presentation to present at a student science conference or write a mock scientific paper in a longer time frame and with more guidance.

for each collaborator (Williams 2002, Spalding et al. 2010). Scientists can use lists of specific items to discuss and agree on with potential educational collaborators before beginning an IBL outreach project, and revisit these periodically (box 1). Being realistic and communicative regarding time commitment and availability is key, as is recognizing that effective partnerships take time to develop. Just as in research, the time required to plan a project scales with the size of the project. Budgeting adequate time prior to implementation can help avoid rushing into projects that can result in poor decisionmaking and foster miscommunication and frustration, ultimately undermining the project's success (Williams 2002, Tanner et al. 2003). Development of strong partnerships in which both scientists and educators feel they contribute their expertise and are supported is a key element of effective IBL programs.

Challenge 3: No experience teaching IBL to K–12 students. *Play to scientists' strengths.* The scientific endeavor *is* IBL, so the IBL approach is an obvious choice that allows scientists to focus on *doing* science with students: asking scientific questions and developing hypotheses, designing studies to test hypotheses, analyzing data and effectively communicating conclusions (table 2). By exposing students to the scientific process, scientists and their educational partners help students learn to view science as a continuous process of discovery rather than a static collection of facts to be memorized (Trautmann 2003, NRC 2005), and students learn how to evaluate scientific evidence and communicate scientific findings (Feinstein et al. 2013).

Make it personal. Scientists' own research is their greatest asset in an educational outreach project. In addition to sharing their knowledge, scientists' passion about their own research is infective, and this excitement about science is one of the most important messages they can share (Petersen 2011). CAMEOS scientists worked with collaborating teachers to develop IBL activities related to their expertise in terrestrial and marine ecology that complemented science curricula (table 3). This allowed them to provide the background information and enthusiasm to support students' scientific inquiries and illustrate aspects of research not typically included in the instruction of the scientific process. For instance, providing personal examples of an unexpected outcome from an experiment can emphasize that falsifying one's alternate hypothesis is interesting rather than bad, a common misconception among students.

Find the right place on the guided–open inquiry continuum. Scientists are often unsure how to translate their

Table 3. Examples of how CAMEOS scientists used their research to engage high school biology students through inquiry projects, varying in time frame, focal skill objectives, and assessment.

	Environmental adaptations of intertidal animals	Pollutant effects on sea turtle health	Temperature effects on tiger moth larval migration	Independent ecological investigations
Equipment	Live organisms	Computer lab, microscopes, and preserved slides	Computer lab and live organisms	Assorted
Time frame	1.5 class hours	5 class hours	10 class hours	38 class hours; 1 full day field trip to symposium
Objectives	Make observations and brainstorm questions	Collect data, use spreadsheet software, analyze data, and communicate results	Develop hypotheses and methods; collect and analyze data	Generate independent research from question to presentation
Approach	The scientist provided background information on rocky intertidal habitats, particularly the environmental conditions that characterize them. She brought intertidal organisms into the classroom. Students observed organisms and recorded their observations. Students discussed hypotheses about how observed morphologies and behaviors might be adaptations to intertidal conditions and recorded a brainstorm of questions to later develop open inquiry projects.	The scientist provided background information on sea turtles, issues of ocean pollution, research question and methods using pictures. Students collected data by counting sea turtle blood cells on preserved slides. Students learned to enter data into spreadsheet software and produce graphs. The scientist shared excerpts from the published paper from same preserved slides, and discussed how scientists communicate their results to other scientists and the public. Student groups then brainstormed how to communicate their results.	The scientist provided background information on tiger moths, habitat, and research question through pictures. Students developed hypotheses. In groups they brainstormed methods to test their hypotheses. After reaching a class consensus on the methods, the scientist brought larvae into the classroom. Each group of students ran one trial. They learned to enter data into spreadsheet software, consolidated their data, and created a graph.	The scientist introduced general ecological concepts matched to high school biology curriculum to students who had completed a guided inquiry unit. Students developed research questions in small groups based on similar interests and devised methods, collected data (ranging from in-class to extracurricular), analyzed data and prepared graphs in the computer lab. The scientist provided equipment, guidance, feedback to students throughout the process.
Assessment	The scientist asked each group of students to share two of their hypotheses and two of their questions with the whole class.	Students turned in graphs they created from their data collection and analysis, and shared their ideas for how to communicate the results with their classmates and the scientist.	Students presented their work to the class and explained if their hypotheses were supported, and why or why not. Students also completed a worksheet with related questions.	Students completed quizzes and homework based on scientific readings, wrote individual research papers, provided verbal feedback to peer groups and gave group presentations at a multi-school symposium.

inquiry-based research expertise to K–12 activities. Guided and open inquiry–based scientific learning is a continuum (figure 1), along which scientist–educator partners can find the right place to provide students with authentic scientific inquiry experiences. For example, inexperienced students with whom scientists have only one or two encounters will not be ready to conduct independent research projects but can gain skills from making observations and brainstorming scientific questions or drawing conclusions from simple graphs of data (figure 1, table 2). At the guided inquiry end of the spectrum, the scientist provides a scientific question and approach and asks students to participate in the steps that fit with predetermined educational goals. In contrast, open inquiry entails mentoring students through an independent science project; students are responsible for developing and executing all stages of the experiment but consult their mentor for resources and advice. Students participating in guided inquiry activities learn specific skills but have less project ownership. In open inquiry, ownership is traded off with factors such as available time, student skill levels, and other constraints (table 1) that may make open inquiry challenging. However, when feasible, open inquiry can be extremely rewarding, because in addition to greater project ownership, students engage in a comprehensive process of independent discovery, critical thinking, and synthesis of their ideas as they move through the entire scientific process. Ideally, students would begin with guided inquiry activities that introduce concepts and skills followed by more open inquiry–based projects applying this knowledge. This sequence requires at least a semester or year of many classroom visits, but guided activities can introduce one or two elements of open inquiry in a shorter time frame (table 3).

Target scientific skills and plan backward. Backward planning is a well-established educational concept that can guide scientists in developing a grade- and time-appropriate IBL activity. Simply put, backward planning starts with identifying learning objectives on the basis of the curriculum, the students' background, and other factors (table 1), followed by creating assessments to evaluate the extent to which students have mastered the targeted skills and concepts (table3). Lessons and activities are devised subsequently to help students achieve the learning goals. Abundant resources are available to support backward planning (see Wiggins and McTighe 2005, Handelsman et al. 2007) and experienced K–12 educators can help guide scientists

Box 1. Example questions.

Through discussions of targeted questions during project planning and assessment, scientists and K–12 educators can hone their project goals and activities.

1. Choosing targeted skills
- What experience do students have with the scientific method?
- What background information do students know relevant to the scientist's field?
- Which concepts related to the scientist's field would be best matched to students' cognitive development?
- What experience do students have with asking scientific questions?
- What mathematical and graphing skills do students have?

2. Determining pedagogical approaches
- Are there English language learners in the class? If so, what techniques does the educator use to ensure they are included and understanding?
- How much variation in skill levels exists among students within the class?
- What techniques has the educator found to be successful in facilitating equal opportunity for participation and learning?
- What technological resources are available and what background do the students have using them?

3. Requesting feedback to enhance teaching efficacy
- Should the scientist adjust content level, quantity, or speed to enhance student comprehension?
- Were there certain concepts or activities that students struggled with the most? What approaches might address these weaknesses?
- Were the scientist's teaching methods effective in soliciting equal participation among students? Are there techniques or activities the educator can suggest to improve this?

through this process. Backward planning can also be used to develop college-level curricula or adapt it for K–12 classes.

Provide structure and continuity. Students who are able to track and reflect on their progress have enriched IBL experiences. Applying techniques to remind students of what they accomplished during their last time spent with the scientist can greatly facilitate student learning, particularly for projects that span multiple classroom visits. Methods as simple as outlining and discussing specific goals on the board at the beginning of the class period and creating checklists before the end provide structure for helping students meet learning objectives. Portfolios (electronic or physical) are familiar to many K–12 students and are excellent tools to organize and archive student projects, as well as to document student progress. Tools for mapping scientific progress provide newer ways for tracking activities, mapping progress, facilitating student discussions of their experiences, visualizing the nonlinearity inherent in the process of science, and practicing metacognitive reflection. CAMEOS scientists used the science flowchart from the *Understanding Science* project (*www.understandingscience.org*), but there are also other techniques adaptable for different student levels and IBL project types (supplemental material).

Ask, so what? By asking, *so what?*, a scientist can motivate students to consider the broader meaning of their scientific research. This includes transferring knowledge to other subjects (e.g., historical and cultural contexts for scientific achievements such as the internal combustion engine or gun powder), as well as transferring concepts to their lives outside the classroom. Students might communicate the implications of their research by writing reflections individually on the meaning of their results, brainstorming with partners or within groups, or presenting their ideas to their peers and broader audiences verbally or visually. Encouraging students to connect their projects to other subjects, as well as the real world not only challenges students to think critically and expand their worldviews but also empowers students to see themselves as capable of impacting the world around them through science.

Share scientific knowledge. Scientists are uniquely positioned to expose K–12 students to the ways scientists communicate their results (e.g., as scientific papers or presentations at conferences) and have them stand up to peer scrutiny, as well as public affirmation. In the CAMEOS program, we hosted a scientific conference at our research institution (Bodega Marine Laboratory; figure 2), during which K–12 students presented their independent research results to a broad audience of students from other schools, resident scientists, and the public. The K–12 students learned to distill their research into the most important points, to reflect on their progress, but most important, the symposium was a powerful confidence builder for the students. Although organizing such events may be beyond the scope of many educational outreach efforts, scientists and their educational partners can support students to give presentations to their classmates or at science fairs. Students can also communicate their research in many other venues, including newspapers, posters and exhibits, and science Web sites.

Promote prospective thinking. So often, students focus on what went wrong and what they would do differently in

Figure 2. High school students present their research projects during the CAMEOS symposium at the University of California, Davis, Bodega Marine Laboratory. The students gain science communication skills, peer feedback, and reflect on the broader implications of their projects. The most valuable outcome is the boost in student self-confidence. Photograph: Dale Trockel.

contrast to what new exploration or question they would tackle next. Retrospection has its place but can stifle prospective thinking and further inquiry, crucial components of scientific advancement. Scientists can challenge students to transfer knowledge gained from one project to a new scientific endeavor—for example, CAMEOS scientists asked students to design a follow-up experiment or mentor new students through a new task reliant on skills they had attained.

Ask for feedback. Just as in research, scientists will be most effective if they welcome constructive feedback to improve their approaches from educational collaborators who have expertise in effective teaching, university colleagues with outreach experience, or contacts in their education department at their institution. CAMEOS scientists often emailed their lesson plans to collaborating K–12 teachers before coming into the classroom and asked teachers how to improve on these plans. After teaching a lesson, CAMEOS scientists asked teachers to share their impressions of how the lesson went and what the scientist could do to improve student engagement and learning in future lessons (box 1). Seeking feedback from K–12 teachers or colleagues on planned lessons and in class management helps scientists become more effective and more efficient in their educational outreach endeavors.

Challenge 4: Making science accessible. *Hone science communication skills*. The best educators have a magical way of engaging their audiences with compelling stories, and this is especially true in K–12 science education. Even the talented few know that effective storytelling requires careful planning and practice and knowing the audience. The first recommendation is always to make it personal and strip out jargon, which is harder than it first appears. Beyond this, graphic representations of scientific concepts, photographs, animations, and other media (e.g., Frankel and DePace 2012) make science more accessible to broader audiences by appealing to diverse learning styles. Many resources are now available to enhance telling a science story (e.g., TED talks, the connection story maker app; Heath and Heath 2008, Olson 2009, Olson et al. 2013). Scientists can use these tools to script the scientific stories they want to tell and then seek out opportunities to practice.

Know the audience. Successful K–12 IBL programs tailor activities to students' experiences and learning environments so that they can develop new skills (table 1). Collaborating K–12 teachers are the first-stop source of information on students' academic backgrounds, as well as cultural and demographic factors that affect how students perceive and participate in science and how these influence classroom dynamics. Scientists can get acquainted with these elements by visiting the classroom as an observer before beginning a project to navigate the unfamiliar K–12 landscape (e.g., in K–12 classrooms lectures typically cannot exceed the allotted time period; topics required by state curricula often cannot be omitted at the expense of other subjects deemed more interesting by teachers or students; long, university-style PowerPoint lectures are foreign in K–12 classrooms). Scientists can also look to prominent teaching and psychology literature for insight into the best teaching strategies (e.g., activity types, conceptual level, language) for particular age groups (supplemental material); however, these resources are best used as complements to—not in lieu of—discussions and planning with K–12 educational partners who have extensive knowledge of teaching pedagogy and their individual students.

Teach for diverse learning styles. K–12 students have remarkably diverse interests and perspectives that might not be familiar to scientists. Lack of engagement from some students could be interpreted as lack of interest when the students are just lacking the appropriate means to express themselves. Using activities with diverse modes of communication (e.g., verbal, written, artistic) in an IBL setting, in which the students are not being graded and the scientist's performance does not influence getting his next grant, can also highlight the creative and fun process of science. For example, CAMEOS scientists encouraged students naturally drawn toward arts or humanities to create illustrations of their methods, produce a time-lapsed video of their experiment, or write a song about their results. Soliciting the students' interests when a scientist introduces himself provides crucial information about the audience and may help the scientist find ways to engage individual students.

Challenge 5: Undervaluation of outreach in academic culture. *Transforming institutional incentives*. Despite recognition of the benefits of outreach and IBL, scientific institutions place lower value on outreach than publications. The skills gained through K–12 outreach make scientists stronger grant writers, researchers, mentors, communicators, collaborators, and educators (Moskal et al. 2007, Spalding et al. 2010), which can offset the commitment required because scientists become more productive while engaging in educational outreach rather than less productive (Thompson et al. 2002, Trautmann and Krasny 2006, Trautmann 2008, Gamse et al. 2010, Ufnar et al. 2012, AAAS 2013).

Shifting the paradigm in academic culture relies on gaining departmental and university-wide support for broader impacts outreach. The NSF and other funding organizations have urged universities to do more to facilitate outreach by scientists (Widener 2012), offering training, incentives, and funding opportunities, and implementing grant requirements such as broader impacts and changing *publications* in NSF biosketches to *products*. Outreach grants can leverage internal resources, such as graduate stipend matches, or attract philanthropy. One very simple way to incentivize outreach is an award, which could be established as a goal of a university's external development program. Scientists and their educational collaborators can publish lesson plans and social science research conducted in the classroom (e.g., Brander et al. 2011). Such publications do not depend on the full support of a university's research infrastructure and the time to publication can be short. Although the valuation of outreach is increasing at many institutions, the lack of university support was recently reported as contributing to the lack of sustainability in several K–12 outreach programs (Ufnar et al. 2012); therefore, much remains to be achieved. For now, tenured professors are perhaps best suited to lead scientist–education initiatives to demonstrate their benefits and change perceptions in the academy. Changing the university *status quo* requires both bold scientists and risk-taking administrators throughout university hierarchies (Anderson et al. 2011).

Conclusions

Collaborative K–12 IBL science outreach programs provide opportunities for scientists to engage in broader impacts by enhancing K–12 student achievement; professional development of scientists and teachers; public scientific literacy; and the missions of universities, school districts, and funding agencies. By incorporating the key elements of adaptability, flexibility, and creativity into their K–12 educational collaborations, scientists can achieve effective and rewarding IBL science outreach while advancing their research and fulfilling their other commitments. As the known benefits gain broader recognition among scientific faculty and their institutions, so will the incentives and rewards. A positive feedback is envisioned in which scientist engagement in educational outreach will simultaneously serve scientists' professional goals and advance US scientific literacy, reducing the growing STEM achievement gap between the US and other nations (Anderson et al. 2011). In conjunction with other local, state, and national STEM educational initiatives, this positive feedback will contribute to maintaining US competition with emerging economies (e.g., BRICS: Brazil, Russia, India, China, and South Africa) and produce the next generation of innovative scientists, prepared to tackle the complex problems facing society in the twenty-first century. Furthermore, in a broader context, many similar challenges can hinder K–12 science outreach internationally. Increased use of these approaches in other countries, as well as the US will progress global scientific advancement and literacy.

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Supplemental material

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