Research Methodologies in Science Education:
Undergraduate Research Mentoring, Teacher Workshops, and K-12 Outreach Activities

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College faculty at liberal arts colleges, comprehensive universities, and research universities all apportion their time between research, teaching and service to the community. While our previous columns have focused on research on science teaching and learning, in this column we explore research that addresses some of the service activities that college faculty undertake. We have chosen to highlight studies that address mentoring undergraduates or teachers in research projects, designing professional development activities for science teachers, and engaging in outreach activities with the K-12 community. The geoscience education community is experiencing an increase in interest in these areas (Figure 1) and the community is now ready to actively promote research in these areas. Although not all faculty will be engaged in all of these activities, we hope that exposure to some of the research in this area will be useful to you as you mentor undergraduates, design, conduct, or plan teacher workshops, or organize K-12 and community educational outreach projects.

We have chosen to focus this discussion on addressing answers to: What are the characteristics that are central to quality research experiences for undergraduates or science teachers? What can you do as a mentor to improve the research experiences of undergraduates in your laboratory? What strategies have been demonstrated to be effective for the professional development of science teachers? How do you decide if the workshops that you have organized for teachers have been effective? What are some of the outreach activities that scientists engage in with the K-12 educational community? How can we ensure that these outreach activities are useful from an educational perspective?

MENTORING UNDERGRADUATE RESEARCHERS

In addition to teaching in a way that promotes active learning, many college faculty offer undergraduates the opportunity to participate in authentic research experiences. A few colleges and universities are also extending these research opportunities to science teachers. Federal funding for undergraduate research, such as NSF's Research Experiences for Undergraduates (REU) program, have increased the opportunities for students to take part in research projects. However, participation in research alone does not necessarily correlate with increased learning and interests. Rather, the quality of a research experience will affect how an individual's interest in science develops, her/his attitudes toward science, and potentially his/her future career goals. Moreover, a quality research experience may develop and strengthen problem-solving skills that will serve the student regardless of their future career path.

Which characteristics, of both the research project and the mentor, will lead to valuable research experiences for undergraduates? Several studies have addressed this question and although this research is still ongoing some generalities are emerging. The guide to mentoring sponsored by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine (1997) defines the goal of mentoring as "advancing the educational and personal growth of the student". This guide advocates a view that mentoring is much more than supervising, and although faculty advisors often will benefit from the interaction, the primary goal should be the intellectual development of the student. Shellito and colleagues (2001) asked undergraduates who had completed an undergraduate research project at a selective public research university to define the characteristics of a good mentor. In addition, the researchers also interviewed experienced faculty mentors to solicit their views on good mentor characteristics. Of the 107 students who responded to the survey, about half engaged in undergraduate research to make themselves competitive for professional and graduate programs, a quarter stated that they were pursuing a personal interest, and another quarter participated because they wanted to experience research firsthand. Although students had differing objectives for participating in research, several aspects of a positive research experience surfaced.

The most important factors to emerge as critical components for quality undergraduate research experiences included: 1) Mentor characteristics, such as the ability to maintain a close mentor/student relationship, mentor availability and commitment to the student's work; 2) Project characteristics, such as projects that fit student's interests and had a reasonable chance of generating quality data; and 3) Appropriate project management, such as a clear expectations on both mentor's and student's parts, continuous guidance and feedback, and effective time management (Table 1, NAS, NAE, IOM, 1997; Shellito et al., 2001; Wade, 2001).

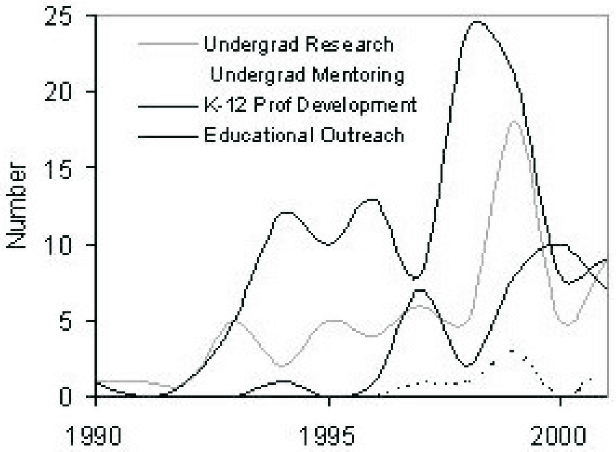

Figure 1. Papers published or presented by geoscience education community on discussed areas from 1990 to 2000. These include only publications or presentations in exclusively geoscience or geoscience education related journals and meetings. Notice that studies of mentoring in undergraduate geoscience research experiences are needed.

1) Mentor characteristics: Both students and experienced mentors considered a mentor that was approachable, encouraging, and supportive as the *critical component* of successful research experiences (Table 1, NAS, NAE, IOM, 1997; Shellito et al., 2001; Wade, 2001). To be successful, a mentor must get to know the student as an individual and spend significant time with the student. This time should be spent discussing both the project and the student's future plans. Additionally, a mentor must be willing to commit the time required to guide the student through an entire project. One experienced mentor summarized her view this way: "Part of being a good mentor is getting to know your students and providing opportunities that will challenge them but not overwhelm them" (Shellito et al., 2001).

2) Project characteristics: In addition to an approachable and available mentor, the research project must be well defined with respect to the student's interests and abilities. Ideally, the project should involve more than just data collection. This does not mean that students cannot conduct a piece of research that is part of a larger research project. However, it does require that the mentor give the student a good introduction to the larger research project, that the mentor makes the student feel that she/he is part of the research team, and that the research experience gives the student the opportunity to analyze collected data, draw conclusions from it and present the results (Table 1, NAS, NAE, IOM, 1997; Shellito et al., 2001; Wade, 2001). Wade (2001) also points out that if a goal is to have students understand the nature of science, then the research experience must be coupled with discussions about the nature of science, because "doing science" alone isn't sufficient to develop an understanding of the nature of science.

3) Project management: The time commitment and expectations on both the mentor's and student's part must be clearly explained (Table 1, NAS, NAE, IOM, 1997; Shellito et al., 2001; Wade, 2001). If the student is expected to sample hourly for a 24 hour period, she/he must understand the commitment required; if the student is really interested in fieldwork, but the project will entail only one field collection and the remainder of the work will be completed in the lab, this must be clearly communicated. The mentor must respect and understand the time commitments (e.g., coursework, part-time jobs, family responsi- bilities) that the student has outside the research collaboration. And finally, the mentor's responsibility does not end when the student is reliably collecting data without supervision – guidance must be continuous. The mentor should be anticipating the next stage in the research process and should confer frequently with the student. The mentor should encourage pre- sentations and or publication of the results of the research and be available for career guidance as well as letters of recommendation after the research project is completed (NAS, NAE, IOM, 1997). The Council on Undergraduate Research offers several resources for faculty interested in providing a valuable research experience for undergraduates (http://www.cur.org/).

PROFESSIONAL DEVELOPMENT FOR TEACHERS

Quality professional development for science teachers is essential for improving student achievement in science (Showers et al., 1987; NCTAF, 1996; Darling-Hammond, 1998; Loucks-Horsley et al., 1998; Loucks-Horseley and Matsumoto, 1999; NRC, 2000; Knight 2002). Improvement is needed both in how we train future science teachers (pre-service; Stein, 2001) and in the quality of ongoing professional training available to teachers once they enter the profession (in-service). The need for professional development of in-service teachers is a growing concern. Every year, almost 50,000 untrained individuals enter teaching with emergency licenses, while 25% of all secondary teachers do not even have a minor in their primary teaching field. In high poverty schools, the incidence of inadequately trained teachers is unfortunately even higher (Loucks-Horseley and Matsumoto, 1999). A recent review of teacher professional development by Loucks-Horsley and Matsumoto (1999) finds very little research that directly ties professional development of teachers with improved student achievement. Instead, much of the voluminous research in this area focuses on how professional development programs lead to change in teacher

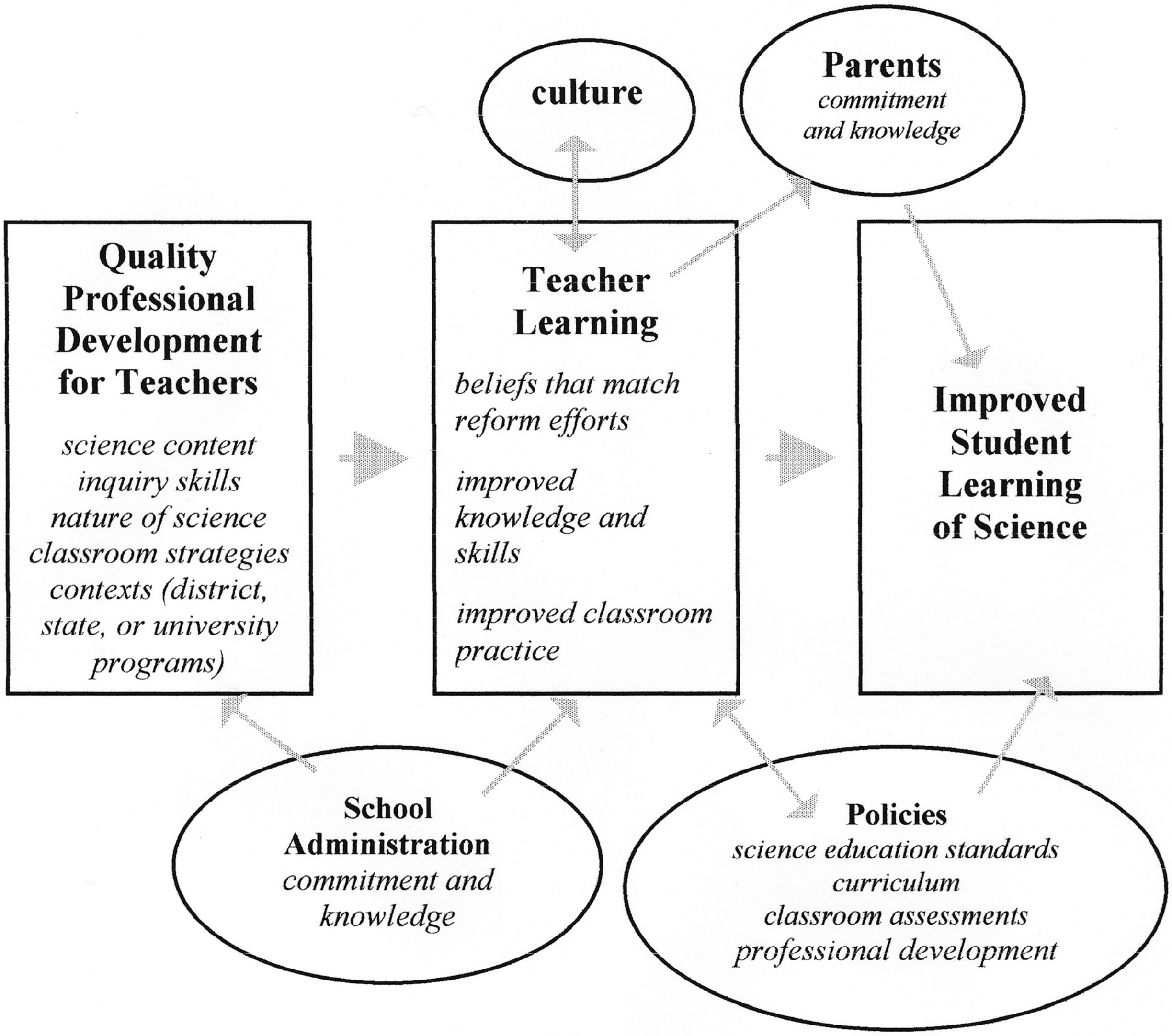

Figure 2. Complex influences on the relationship between teacher professional development and student learning (modified from Loucks-Horsley and Matsumoto 1999).

knowledge, skills, and teaching practices. Teacher professional development programs are offered in many different contexts, including school district mandated programs, state mandated programs, and programs designed by university science educators or scientists. Many school districts and states do not evaluate the quality of professional development nor improvements in student learning. Rather most schools evaluate compliance: Is some form of mandated professional development for teachers in place? In the space of this column we cannot adequately review all the research on professional development for teachers but we strongly suggest the interested reader begin with the book by Loucks-Horseley et al. (1998), and the review by Loucks-Horseley and Matsumoto (1999).

A review of 450 teacher professional development projects by the National Staff Development Council found that 90% included no evaluation of student learning (Killion 1998, Loucks-Horsley and Matsumoto 1999). Indeed, designing and collecting data that links professional development of teachers and improved student learning is difficult as there are many factors that influence student learning (Loucks-Horsley and Matsumoto, 1999, see Figure 2). Additionally, studies that will use K-12 student data must comply with federal "human subjects protection" guidelines which require signed consent forms from each student and their parents. Getting such a research project through institutional human subjects committees can be time-consuming, but is vital and we will discuss this

Component	Particulars
Collegial Relationship Between Student and Mentor	get to know the students personally - their interests, goals, background; develop a relationship based on mutual respect and trust
Availability of Mentor	be approachable and available; provide lots of encouragement and constructive and laudatory feedback
Nature of Project	tailor a project to student's interests, motivation, and ability; make sure the experience involves more than just data collection; couple the research activities with discussions of the nature of science to give student a deeper understanding of science
Clear Expectations	be very clear on how much time the project will require and determine if this aligns with student's motivation, schedule, and other commitments; be clear about student's responsibilities as well as the requirements for authorship of presentations or publications
Continuous Guidance and Support	meet with student regularly to discuss progress and problems; provide student with all materials needed to do the research; provide time and access for student to join lab meetings, attend research seminars, research conferences, and other venues that will contribute to student's intellectual development
Time and Project Management	choose a project that can be completed during a defined time period and set guidelines and dates for projected completion of each component of the research; prioritize tasks

Table 1. Critical components of quality undergraduate research experiences (summarized from NAS, NAE, IOM, 1997; Shellito et al., 2001; Wade, 2001).

issue in a future column. Although many projects ignore the issue of student learning, existing research indicates that many factors outside of the teacher and the student have been found to influence both teacher and student learning (Loucks-Horseley et al., 1998; Loucks- Horseley and Matsumoto, 1999). Teacher's beliefs and their prior experiences as well as the support they receive from school administrators, parents, and fellow teachers will affect teacher learning (Figure 2, Loucks-Horseley and Matsumoto, 1999; NRC, 2000). Many teachers hold deep-seated beliefs that knowledge is a collection of facts, that learning is memorizing, and that teaching is best accomplished by telling rather than initiating inquiry (Loucks-Horseley et al., 1998; NRC, 2000). Clearly, these beliefs are at odds with current science education reform efforts. Changing teacher beliefs and practices is not a simple task and will take considerable time (Loucks-Horsley et al., 1998; Loucks-Horseley and Matsumoto, 1999; Luft, 2001). For example, a study of a university sponsored professional development program indicated that changes were directly tied to teacher experience. Specifically, during a year focused on increasing science teachers' familiarity with and classroom use of inquiry-based teaching strategies, novice teachers did not significantly increase their use of these strategies whereas experienced teachers showed changes both in beliefs and classroom practice (Luft, 2001). The implication is that novice teachers will need more than one year of professional development in order to change their teaching practices to match those advocated in reform efforts. We should point out that this program is unique in its length; most professional development activities take the form of workshops that span only one or two weeks, and provide no follow-up activities. A good example of a typical Earth Science workshop is described in Levitt and Manner (2001).

Scientists are often involved in teacher professional development by teaching summer courses or involving teachers in authentic research projects. One would think that collaborations between scientists and science teachers are bound to be successful, but this is not always the case. Sometimes scientists overlook the strengths that teachers bring, such as their ability to introduce scientific ideas to students in age-appropriate ways, an ability

Critical Components	Suggested Activities
1. Reliable Access to Researchers	classroom visits by scientists; teacher workshops and field trips lead by scientists; student congresses; email interactions; teleconferences between students and scientists
2. Continuous Training Sessions and Workshops	teacher training workshops; semi-annual meetings for teachers to discuss latest data analyses; student congresses to present student data
3. Articulation Between Science Education Standards (National and State) and Assessment of Student Learning	provide a matrix of science content and skills that can be developed by collaboration in research partnership and how these match state and national science education standards; provide examples of assessment activities; allow sufficient time for teachers to collaboratively construct common student assessments for concepts and skills taught
4. Well Designed Research Protocols and Introductory Materials	clearly organize the introductory materials and research protocols; provide sample teacher lesson plans; monitor data quality and modify research protocols if there are problems
5. Access to Research Equipment and Materials and Information on Potential Funding Opportunities	provide information on the time commitment involved; provide a list of materials needed and potential costs to teachers; explain if/how equipment loans will be handled; provide a list of potential funding sources such as federal funds, school district funds or community business grants

Table 2. Critical components of successful Student-Teacher-Scientist Partnerships (paraphrased from Evans et al. 2001).

lacking in many scientists (NCTE, 2001). When working with teachers, it is essential to develop a collegial and respectful atmosphere from the beginning. A blueprint for developing teacher workshops about biological evolution has been developed by UC-Berkeley paleontologists and science educators (NCTE, 2001). These authors raise issues that scientists should consider when developing teacher workshops on other topics.

Two of the most important factors that influence student learning are teachers' understanding of the classroom implications of cognitive theories of teaching and learning and small class sizes (NCTAF, 1996; Darling-Hammond, 1998). The National Research Council (2000) suggests that teachers need a sound foundation in the major ideas of the discipline they teach as well as an understanding of how students come to learn those ideas. Teacher professional development programs that helped teachers learn how their students come to understand the subject matter were most effective at improving student achievement (Loucks-Horsley and Matsumoto, 1999). Loucks-Horsley and Matsumoto (1999) state that quality professional development for teachers should model how teachers should teach their students and therefore should utilize "active engagement, learning over time, and opportunities to practice and apply what is learned to their own classroom". There is no "one size fits all" model; professional development must be tailored to the unique situation in which the teachers work.

EDUCATIONAL OUTREACH ACTIVITIES

Science faculty undertake a wide variety of educational outreach activities as part of their service to the community. This outreach ranges from short-term interactions, such as serving as science fair judges or visiting classrooms, to large-scale federally funded projects that involve K-12 teachers, students, or the general public in active, extended research projects. As the federal funding for "informal science education" has increased, the number and diversity of research projects involving scientists in partnership with teachers, K-12 students, and the general public have expanded. Although the current research base on these partnerships is small, it will grow in the near future, as federal agencies require evaluation of all funded projects.

We have chosen to highlight a few of the projects for which some research is available, both published and in papers presented at research conferences. Publication in science education journals typically takes about two years from submission to publication, therefore for conference papers we provide a web site or email address where electronic copies of the paper can be obtained.

Student-Teacher-Scientist Partnerships - Monitoring volcanoes in Hawaii, excavating Ice Age mastodon fossils in New York, or studying the impact of El Niño and La Niña events on ocean ecosystems are a few exciting ways to get K-12 students involved in science. In recent years a number of research partnerships have been formed between students, teachers, and scientists. These research partnerships have multiple goals: to collect scientific data from a large geographical area that would not be tractable without the partnership and to develop K-12 students' scientific inquiry skills, understanding of the nature of science, as well as their understanding of important science concepts (Duchovnay and Joyce, 2000). There are several Earth Research Partnerships, e.g., the "Mastodon Excavations" and "Devonian Seas" projects at the Paleontological Research Institute in Ithaca, New York; however research on these partnerships has not yet been published. A forthcoming issue (early 2003) of the Journal of Geoscience Education will be devoted to research partnerships. Evans and colleagues (2001) describe one example of such a student-teacher-scientist partnership in biology/ environmental science – the Forest Watch Program – and describe the critical components for successful partnerships from the participating teacher's point of view (summarized in Table 2). Scientists who are involved in such partnerships or who are planning on developing such partnerships in the future should be aware of this research.

Forest Watch started in 1992 and currently involves students from more than 100 New England schools (Evans et al., 2001). The students and teachers collect annual data on the growth and health of tagged white pine trees in marked study plots near their schools. The data are used by scientists who are testing the hypothesis that increased ground-level ozone concentrations are correlated with pine needle damage and con- sequently stunted tree growth. Students take measurements of their tagged pine trees and collect needles to send to their scientist collaborators. Each year the scientists compile all the data and convene teacher workshops as well as student congresses.

The success of this program is primarily due to opportunities for personal interaction. The teachers who participated in this research collaboration feel that access to the scientists is critical for success (Evans et al., 2001, Table 2). Science is a collaborative enterprise and teachers needed to be able to discuss their questions, observations, and concerns with the scientists; they suggest that classroom visits by scientists were hugely motivating for both teachers and students (Evans et al., 2001) and increased the quality of the student-collected data (Lawless and Rock, 1998). Teacher workshops and conferences where teachers were able to interact with one another and received the latest training in research protocols as well as summaries of the latest data were also important for success of the collaboration (Evans et al., 2001, Table 2). The Forest Watch program also incorporated "student congresses" where students from different schools came together to present their results and analyze combined data sets.

To ensure reliable data that will be of use to scientists, it is critical that the introductory materials and protocols are clear and well organized (Evans et al., 2001, Table 2); detailed guidelines for organizing protocol materials are presented in Wormstead (1999). It often helps to pilot a protocol to determine if it is suitable for the age group that it is intended for; teacher input can also help ensure that materials are age-appropriate. Teachers need to know what data are critical for the scientists and they need the freedom to add additional components to meet their own educational objectives for their students. It is important that students are allowed to address their own questions within the context of their field site. Many teachers found a categorization of how the research project met state and national science education standards useful and they appreciated potential student assessments that could be used in their classrooms (Evans et al., 2001, Table 2). They valued being able to collaboratively develop student assessment activities with other teachers for each concept/research skill that students used in the research project. Most importantly, the teachers felt that the partnership must not leave students with a sense that doing science is only "collecting data" (Evans et al., 2001). Lastly, teachers needed to know the time commitment and material supplies needed for the partnership up front (Evans et al., 2001, Table 2). Teachers must know whether materials will be supplied or must be purchased and if needed equipment can be loaned for short periods of time. If teachers get this information at the beginning, they can apply for small grants from their districts. One Forest Watch teacher applied for a grant from the local electric company and purchased a video projection unit so that her students had the technology to display their research presentations in class (Evans et al., 2001). Other scientific organizations have found novel ways to fund outreach (e.g., Kopaska-Merkel, 2001) and it is important to remember that K-12 classroom budgets are much smaller than those enjoyed at universities.

What benefits do scientists derive from partnerships with K-12 students and teachers? Tanner (2000) interviewed faculty, graduate students, and postdoctoral research fellows to find out what benefits they obtained from their collaborations with K-12 students and teachers. Tanner (2000) found that the benefits were diverse but could be categorized into three classes: benefits as scientific professionals, benefits as educators, and benefits as individuals. Many scientists felt that their own enthusiasm for science was rekindled by working with children; the interaction made them think about science more broadly, and they developed the ability to explain science in simple terms. Some stated that they developed a new appreciation for the challenges that teachers face and felt the experience honed their skills for teaching undergraduates. Some scientists realized that they really are role models for students. Finally, many felt personal satisfaction in working with children and appreciated the opportunity to think outside their own narrow research specialty.

How do such research partnerships between scientists, teachers and K-12 students increase student learning of science? These data are not yet available but will hopefully be forthcoming in the next few years as newly formed research partnerships evolve and formative and summative program evaluation continues.

Teaching Fellows in K-12 Schools/Community Centers - Are there other ways to engage K-12 students and teachers in science beyond the research partnerships described above? Small-scale projects encouraging undergraduate outreach into K-12 classrooms have existed for years (e.g., Domack, 2000). These programs are typically voluntary, although some faculty have implemented a service component into their geoscience major courses. However, these programs were almost exclusively informal, and benefits to participating students were limited to personal satisfaction. Recently, NSF funded several large projects that place graduate students and advanced undergraduates as "teaching fellows" in local schools. These so-called "GK-12" grants are designed to improve student learning in science, mathematics, and engineering in local schools while training future college faculty in teaching strategies and engaging them in outreach activities early in their careers. The research from the GK-12 projects is not yet in, as the oldest projects are just in their third year. However, Trautmann and colleagues (2002) recently presented some research on how their teaching fellows are interacting with local science teachers in rural New York. The teaching fellows have been co-developing inquiry lessons based on their research expertise and the cooperating teachers' interests. Additionally, fellows helped modify existing labs to improve student engagement and developed lessons on the nature of science. Trautmann et al. (2002) found that the fellows can help teachers overcome barriers to inquiry-based teaching in the K-12 classroom and served as positive role models, bringing multicultural perspectives to students in rural areas who were not often exposed to individuals with life experiences different from their own.

Finkelstein (2000), funded by an NSF postdoctoral fellowship in science education (PFSMETE program) developed a physics course that integrated student learning of physics and theories of teaching and learning, community outreach, and physics education research. He forged a collaboration between the physics department and the college of education at the research institution that hosted him during his fellowship tenure. We think that his approach is worth replicating in other disciplines. Briefly, his course introduced undergraduates (all pre-service teachers) to important physics concepts, to cognitive theories of learning, and to research on physics education. Students were then required to develop lessons to teach junior and high school students the same concepts that they were themselves struggling to understand. Additionally, the students were obliged to modify curriculum so that it would be appropriate for both in school settings and in after school community centers. This approach forced students to first understand the material and then wrestle with how to teach the material given the experiences and cognitive abilities of their students. Finkelstein's (2000) research suggests that teaching a topic "forces an additional level of reflection both upon the science content and one's own mastery of that content". We think similar courses for future science teachers in a variety of disciplines could have dramatic effects on the learning of science in future K-12 classrooms. Of course, additional research on whether such an approach leads to the intended outcome is needed.

CONCLUSIONS AND FUTURE DIRECTIONS

It is clear from the preceding discussion that faculty can have a profound impact on students outside of the traditional college classroom. Whether faculty choose to interact with teachers, K-12 students, undergraduates, or the general public, a carefully designed project, such as those discussed here, can have profound impacts on the public's science attitudes and scientific literacy. More research into the impact of the mentor-student relationship on the success of undergraduate research experiences is needed (Figure 1). Additionally, the impact of teacher professional development on the learning and attitudes of K-12 students, especially in the geosciences, would be beneficial. Although a number of funding opportunities in all areas of outreach and student research exist, it is becoming clear that attention must be paid to determining the effectiveness of these endeavors. We hope that the studies highlighted here will guide the direction of your outreach programs and research.

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We welcome comments from Journal of Geoscience Education readers about this column or any previous column as well as suggestions for topics to address in future columns. Please email us (or the editor) directly with your critiques, comments, and suggestions.