MAXIMIZING THE IMPACT OF PROFESSIONAL DEVELOPMENT FOR EARTH SCIENCE TEACHERS

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Abstract

This study examines the extent to which follow-up sessions can provide support for earth science teachers as they apply what they learn from professional development coursework during the academic year with their own students. Data include direct observation of follow-up sessions of courses for teachers; interviews with course co-instructors and teacher participants; and, document analysis of teacher products with a focus on the lesson plans, laboratory/activity sheets for students, and virtual field trips that teacher participants submitted and shared during follow-up sessions. Strategies are recommended to assist earth science content faculty in increasing the impact of their work with teachers and hence, student instruction.

Introduction

The federal No Child Left Behind legislation of 2001 and funding is primarily concerned with K-12 student academic achievement and emphasizes the need for teachers to be adequately prepared in the particular content area they teach. As a result, this funding source is regularly used by states to conduct professional development for in-service teachers in the form of courses and seminars designed to help them become more effective in the classroom. While the federal No Child Left Behind legislation of 2001 emphasizes content knowledge preparation for teachers, teacher effectiveness research is firmly grounded in the need for both subject matter knowledge and instructional skills. Through an intensive study of achievement scores of students, Ferguson found that teacher content knowledge is positively correlated with student achievement [1]. Darling-Hammond found that well-prepared teachers have the largest positive impact on high student achievement, and that teacher preparation needs to include both subject area knowledge and pedagogical training [2,3]. Particular types of pedagogical training have been researched to determine their effectiveness. In the study, *How Teaching Matters*, the Educational Testing Service found that student achievement increases over 40% of a grade level when teachers are skilled in utilizing hands-on activities with students and by over 40% of a grade level when teachers receive training in laboratory skills [4]. Interestingly, a comprehensive study of teacher development programs offered through Eisenhower grant funds found that teacher training in content, or pedagogy alone, does not necessarily result in improved student performance when the teacher re-enters the classroom [5]. However, positive gains in student achievement occur when professional development blends content preparation and instructional strategies for how to teach that content to students. Additionally, the study found that if the true goal of the professional development is to produce tangible change in teacher practice in order to positively influence student achievement, then professional development efforts need to have extended contact hours occurring over several months.

Each summer, teachers participate in professional development designed to make them more effective in the classroom. Based on a review of the literature, follow-up sessions during the academic year are needed to support teachers' use during the academic year of what they learned during the summer. Follow-up sessions can be crafted in such as way as to document teachers' use of their training in their own classrooms while providing continuing training and support. Through the requirements and activities of these follow-up sessions, middle and high school students' work can be examined using ongoing student assessment and reflection to determine the impact of the training on student learning and the continued learning needs of the teachers and their students. Not only does this data benefit those responsible for the design and implementation of teacher professional development programs by providing valuable feedback on their effectiveness, but teachers also can utilize the data to improve their own practice to better enhance student learning. The Educational Testing Service found that student achievement increases by 92% of a grade level when teachers effectively use research-based assessment strategies [4]. The National Board for Professional Teaching Standards (NBPTS), which serves as the primary licensing board for the field of teacher education, recognizes the positive association between reflective practice and student achievement [6].

Standards for Earth Science Instruction

Research indicates that coherent programs of teacher professional development align with national, state, and local standards, thus facilitating efforts to improve practice [5]. In these times of accountability, teachers will ignore training they perceive as disconnected from the standards that they have to implement. The *National Science Education Standards* highlight expectations for "Earth and Space Science" content and skills at all grade levels [7]. While identifying concepts and skills appropriate for instruction, the *National Science Education Standards* provide standards for how to teach, and how both students and teachers should be assessed. Teachers are mandated to use a hands-on, inquiry-based approach in their teaching through a purposeful mix of guided discovery, direct instruction tied to guided discovery experiences, and student-generated investigation. Hands-on experience is viewed as the foundation for student learning at all grade levels and integral to students' construction of scientific understanding. In terms of how science teachers and students should be assessed, the *National Science Education Standards* identify a set of standards for the assessment of students, teachers, schools, and school districts that is solidly grounded in using a variety of assessments of student performance to inform decision making at the classroom, school, and district levels.

More important to most teachers are state standards and, if their school division has them, local standards. The *Science Standards of Learning for Virginia Public Schools* were developed by a team of scientists and science educators to determine what the students of Virginia need to know and be able to do at each grade level, K-12 [8]. While earth science content is found in each of the K-6 grade levels, the science for grades 7-12 is divided into courses by domain specific areas (life science, physical science, earth science, biology, chemistry, and physics). School divisions may adjust the order of these subject area domains to best meet the needs of their student and teacher populations and community needs. In Virginia, earth science includes geology, oceanography, meteorology, and astronomy concepts and skills. The science standards in Virginia are aligned with the national science standards.

To complicate matters for teacher educators while simplifying matters for practicing teachers, school divisions have developed curriculum guides which further describe which concepts and skills in earth science should be taught and when. Teachers' adherence to the division's curriculum guide varies from school division to school division, and even from school to school, with some forced to follow the curriculum guide explicitly. Some schools and school divisions mandate classroom activities while others allow flexibility in adapting the guide to their particular students' needs, their own interests and strengths as teachers, and more frequently, to the extent to which particular topics are "covered" on *Standards of Learning* (*SOL*) tests. The coherence of professional development programs with state and local teaching, and assessment standards facilitate extensions and improvement of teaching practices as well as teacher buy-in.

Professional Development Needs in Context of Teacher Shortage

The professional development needs of in-service science teachers have changed in response to the hiring and retention practices of school districts during the current science teacher shortage. Training for fully licensed science teachers has historically included training in content. For example, the National Science Foundation (NSF) has a long history of funding content training for science teachers in various science disciplines. The emphasis of these programs was to support practicing teachers' understanding of science as a growing and changing field so that the science they taught would be current. This approach assumes the participating teachers have the time and expertise in pedagogy and can easily translate their learning from these programs back into the classroom as effective experiences for students.

However, the science teacher turnover rate has increased to approximately 15% annually. Coupled with a shortage of teachers prepared for these positions, this necessitates hiring uncertified and ill-prepared teachers [9]. For example, in 2003-2004 over half of the secondary schools in the United States reported science teacher vacancies, with 31% finding it very difficult or impossible to fill science positions in the non-life sciences. As a result, 26% of secondary schools hire teachers that do not meet their state requirements for licensure and 34% use substitute teachers to fill vacancies [10]. Existing adjustments in licensure regulations and school hiring practices aimed at getting science teachers into the classroom more quickly almost ensure that new science teachers are not prepared in teaching strategies. Today, it is common for practicing science teachers to lack pedagogy training in how to effectively teach science. For example, current licensure regulations in Virginia require that teachers have pedagogy training for the grade levels that they will teach, but they are not required to have training in how to specifically teach science. In high needs science areas, such as earth science, teachers have varying degrees of content training and professional experience in earth science and training in how to teach students. The worst case scenario is that they have inadequate or no content training in any of the earth science disciplines, and have absolutely no training in how to teach students at an appropriate level. Earth science teachers need professional development in both content knowledge and pedagogical strategies.

Even teachers who have extensive coursework in all of the earth science disciplines may lack the content fluency and flexibility required to create appropriate, meaningful learning experiences for students. Teaching requires thinking about science content differently. In this case, the teacher possesses content knowledge, but needs to develop what is referred to as "pedagogical content knowledge." [11] This type of content knowledge includes earth science facts and skills, as well as an understanding of the overall structure of how the facts and skills fit together in a meaningful way for learners. Additionally, teachers need to develop pedagogical knowledge of how to teach students.

The earth science content knowledge of teachers can be measured during the summer portion of the professional development training; but, determining whether this knowledge is actually extended to students during the academic year requires continued assessment by the teachers. Since the ultimate goal is student learning, teacher training needs to include implementation into the classroom of science content and skills learned during the summer and taught during the academic year in an effective manner. High-stakes testing is a reality for Virginia's teachers, but teachers cannot wait for the *SOL* test results to ascertain their effectiveness. As a result, teachers must be trained in how to improve their teaching based on their ongoing assessment of student work.

Virginia Earth Science Collaborative

A set of five professional development courses for in-service teachers is offered statewide that addresses each of the major disciplines in earth science: *Astronomy*, *Geology*, *Meteorology*, and *Oceanography*. Also included is an advanced geology course that is specific to the *Geology of Virginia*. Each course was developed by a team of secondary earth science teachers, along with university faculty with expertise in the specific earth science. These courses are not simply content courses commonly offered at each participating institution. Instead, an emphasis is placed on ensuring that each course addresses specific content that is pertinent to teachers in an effort to support their content and pedagogical content knowledge growth. A common syllabus is utilized across Virginia for each of the five courses. Courses include common field trips designed to support teachers' understanding of course content, as well as increase their knowledge and use of resources in Virginia with their own middle and high school students. With an emphasis on both training in pedagogical content and pedagogical skills, university faculty co-teach each course with an in-service earth science teacher with extensive experience teaching earth science in middle and/or high school. In some cases, the university content faculty member also has experience in teaching earth science to middle and high school students. Professional development courses are offered primarily in the summer with follow-up during the academic year.

Purpose of Follow-up Sessions

During the summer portion of the course, emphasis is placed on improving teachers' personal content knowledge in earth science. However, the purpose of teacher training is to improve middle and high school student performance. This means that assessing and supporting teachers' pedagogical content knowledge is even more important since this is the type of knowledge that will directly impact students. While multiple-choice tests can determine the extent to which the teachers increase their personal content knowledge, pedagogical content knowledge must be measured differently. Instead, pedagogical content knowledge can be assessed via their creation of products for use with students; such as, lesson plans, laboratory activities, virtual field trips (a series of *PowerPoint* slides illustrating a geographic locale that the students are unable to physically visit), assignments, and *PowerPoint* lecture slides. It can also be assessed by directly observing them teach or through videotaping. During follow-up sessions, teachers document and share with their course instructors and peers the implementation of their learning into their classroom instruction and the results of their efforts to improve student learning. The follow-up sessions also provide opportunities for course instructors to measure the impact of their efforts on teachers' pedagogical content knowledge. These sessions also give professional educators a structured opportunity to reflect and improve upon their teaching practices in light of their impact on student learning, and to do so with the support of their teaching peers enrolled in the professional development course.

Follow-up Session Assignments

Appropriate assignments for teachers to complete, share, and discuss at follow-up sessions include lesson planning, unit planning, designing inquiry-based laboratory activities for students, creating *PowerPoint* slides for lectures, and creating virtual field trips to create a diverse set of opportunities to assess student learning. These can be critiqued by peers and course instructors. Additionally, teachers should be required to gather, analyze, and reflect on their students' performance on these products when implemented in the middle and high school classrooms [12]. These assignments are grounded in experiences that allow teachers to use their content knowledge and pedagogical knowledge while reflecting on the impact of their efforts on student learning. Additionally, these assignments can provide a way for the co-instructors of the course to identify teachers' science misconceptions. Exposed to new content during the summer portion of the course, teachers need opportunities to practice applying what they have learned in a manner consistent with standards-based instruction, which specifies that students should be taught science concepts through hands-on, inquiry-based experiences. Sometimes while trying to create hands-on, inquiry-based learning situations for students, teachers have to link concepts together or formulate them in different ways other than how they were originally exposed to them during the summer portion of the course. Course instructors can provide meaningful feedback to teachers on their application of course content to the middle and high school classrooms so that the content taught in schools is accurate while consistent with a hands-on, inquiry-based approach to middle and/or high school earth science instruction.

As experts in content, co-instructors can work together to help teachers identify additional ways in which their products, shared during follow-up sessions, can be grounded in a meaningful, real-world context for students that is consistent with the way in which science is practiced by scientists in the field. Teachers may not be as adept at making connections between the course content that is new to them and real-world applications even though this is desperately needed in order to provide a meaningful experience for students. At follow-up sessions, when teachers share their classroom implementation experiences, co-instructors can highlight real-world connections that teachers have shared, or brainstorm with teachers the connections that they could make while teaching. Additionally, the state and national science education standards identify the need for teachers to teach students in a manner such that they learn about the nature of science as it is practiced by scientists. As with real-world connections, earth scientists serving as co-instructors can use follow-up experiences and assignments in their course as a way to help teachers better represent the nature of science as an investigative field of study to their students.

Looking at Students' Work to Improve Teaching

Each of the previous follow-up tasks assists teachers in examining their practices in terms of their impact on student learning. In an age of accountability, teachers must look to student performance as an indicator of their success in teaching as well as use it to drive future instruction efforts. Through analyzing the various lesson plans, unit plans, inquiry-based activity sheets for students, *PowerPoint* presentations for lectures, and virtual field trips that teachers create, co-instructors can determine weaknesses and misconceptions in teachers' content knowledge. As misconceptions in teachers' knowledge are identified, they can be discussed in terms of also being likely for students. Additionally, teachers can be asked to provide and analyze student performance on these from their classrooms.

This can be embedded easily into the follow-up sessions if teachers are provided guidance for this task during the summer. Teachers will need to create at least two lesson plans with all student activities and teaching support materials that they will implement in their classrooms. They also need to design pre- and post-assessments to determine if their students have learned the earth science concepts they are attempting to teach. Teachers not specifically assigned to teach earth science, or who are teaching with an earth science pacing guide that does not allow for the topic of the course to be taught during the time in which the follow-up sessions occur, must consult with the instructor to find a way in which to link what they have learned during the summer to their curriculum. This flexibility is key to adapting assignments to the teachers' actual teaching situations and in some cases, learning about science connections that are unfamiliar to the teachers. This same flexibility also requires teachers to be held accountable for implementing what they have learned, hence updating instruction. In addition to turning in all teaching materials to conduct the lessons, teachers should be instructed to turn in samples of student work. Consider having one lesson planned in small groups (two to three teachers) who teach similar (hopefully identical) grade levels. They plan every aspect of the lesson together and plan to implement it identically in their classes. In this way, they can compare and share samples of student work in their analyses. The other lesson they may do individually. During the follow-up sessions, teachers present actual samples of student work and the findings of their analyses in terms of what worked, what didn't, and suggestions for future teaching efforts in light of their impact on student learning. Since instruction for all students is important, showing samples of work for students who show understanding and those who are struggling can prompt lively discussions and brainstorming. During these sessions, teachers expand their teaching ideas to help all students learn. Instructions for teachers are provided in Table 1.

Table 1
Reflecting and Growing from Student Work

Task	**Considerations**
Reflect on **your teaching** by writing an approximately 300-word reflection on the student assignment you developed.	• What did you do and how did you do it? • What worked well (from *your* perspective as the teacher)? • What needs to be changed? • How would you change it?
Analyze **student learning** by collecting samples of student work. Collect three samples of student work, one from the top third, one from the middle third, and one from the bottom third of the class. Write directly on each work sample (photocopy or original) pointing out what the student understands, doesn't understand, and as appropriate what else you might try to do to help the student learn. In addition, you will write a short summary (300-500 words) of your analysis and compare the three students.	• What *SOL* concept did you target? • What did your students understand about the concept? • What did your students not understand about the concept? • How can you prove what your students understand of the *SOL* from the student work you brought?

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Sources of Data

Data collection included the following: direct observation of follow-up sessions of *Geology* and *Oceanography*; interviews with course co-instructors of *Geology*, *Oceanography*, and *Astronomy*; interviews with teacher participants from *Geology* and *Oceanography*; and, document analysis of teacher products with a focus on lesson plans, laboratory/activity sheets for students, and virtual field trips from *Geology* and *Oceanography*. All courses examined were offered as part of the Virginia Earth Science Collaborative (VESC) and were held at a suburban university in northern Virginia.

Findings and Recommendations

Teachers produced an abundance of products related to their experiences in the professional development courses. Careful planning and scheduling of follow-up support encourages teachers' continued progress to positively impact student learning.

Quality of Products: Inquiry-Based and Relevant

Lesson plans and other products submitted by teachers varied greatly with respect to the extent to which they were inquiry-based and relevant. When teachers enrolled in content courses submit lesson plans and other materials to document the application of their learning to their classroom instruction, the work should be examined carefully to determine if the lessons and other materials are inquiry-based or just traditional, teacher-directed instruction. Lesson plans frequently consisted of a laboratory experience validating what the students were told by the teacher during prior instruction. This is not inquiry-based science. Also, lesson plans should be examined to determine the extent to which the connections are being made between what the students are learning and real-world importance. Among the lesson plans analyzed, it was noted that the clarity of these connections varied. Virtual field trips were much more likely to make explicit connections between real-world relevance and earth science knowledge than lesson plans and laboratory experiences.

Teachers need to be supported in designing products that create relevant, hands-on, inquiry-based learning experiences for students. As potential novices in their content area, it is difficult for many teachers to creatively develop situations that structure students' learning in this way. Pedagogical content knowledge is the type of content knowledge teachers use when they create a laboratory activity or virtual field trip experience for students. This requires that teachers not only be able to think of ways in which concepts and ideas can be concretely modeled, but also be familiar with the ways in which the concepts and ideas relate to the students' real world and interests. Based on our findings, creating a virtual field trip is an appropriate and effective task for supporting teachers as they apply their new content knowledge to the classroom setting. Even creating a *PowerPoint* presentation requires that the teacher think about the logical order in which ideas should be presented, the way in which these ideas are related, and the real-world significance of the topic. However, teachers need explicit instruction in how to make virtual field trips and lecture presentations more student-centered through visually stimulating graphics and images by using discussion questions, relating ideas to previous experiences in class, and relating content to the lives and interests of students. Teachers also need instruction on how to use lectures to support student inquiry by using them as an instructional technique *after* exploratory hands-on activities.

While findings illustrate that lesson planning (and unit planning) tasks were less effective in helping teachers apply their new content knowledge in an inquiry-based and relevant fashion, the reality is that lesson and unit planning are the foundations of teaching. As novices in their content, it may be less frightening for the teacher to lecture on a topic and then do a follow-up lab activity. In this manner, the lab experience is meant to have students validate what they learned from the teacher and textbook. The problem with this approach is that it is in direct conflict with the way in which teachers are encouraged to teach according to the national and state science education standards. Ideally, teachers are supposed to provide experiences in their classrooms from which students construct their knowledge by asking questions and then exploring topics within the context of their questions.

Through our work, we have found a simple strategy for supporting teachers new to science teaching and/or new to their content area who are struggling with creating inquiry-based experiences for students: give the students the lab activity *before* the lecture with just enough direction to keep them safe! As students perform the activity, they should keep a log of the questions that arise. The lab activity becomes an engagement/exploratory activity. The lecture can then be grounded in the context of the students' experiences and the questions they generated during the lab. After the lecture and class discussion, students need opportunities to apply what they have learned through further teacher-generated and student-generated investigations.

Often lab activities provided in teacher resources and on-line are "cookbook" labs where the student is instructed to follow a set of steps to get a particular outcome so that they can answer a particular set of questions. The cookbook lab can be modified to better support an inquiry-based learning experience rather than a validation-type experience. An easy solution is to remove parts of cookbook lab directions for students. For example, students might receive a set of laboratory directions that gives them the research question, hypothesis, data table, and analysis questions, but students have to generate the procedure. In another more complex assignment, students might receive the research question, data table, and analysis questions, but they have to generate the hypothesis and procedure. A third option is to provide only the research and analysis questions—the students must construct their own hypotheses, procedures, and data tables—thus increasing not only the degree of difficulty, but intensifying the inquiry-based learning method.

As novices in their content, the best the teacher may be able to do is locate "cool" and relevant laboratory activities from the Internet, their fellow teachers, or their teaching resources. Often, these laboratory activities will be cookbook labs that may or may not fit perfectly. As experts in the content area, the course instructors can be instrumental in helping the teachers understand ways in which labs can be modified to fit topics of study more appropriately and support a student-generated investigative experience.

Scope of Teachers' Products: Broad versus Focused

Interviews with co-instructors reveal that frequently, teachers requested that they work on assignments so that the outcome would be a set of teaching materials that spanned the entire course curriculum. For example, when teachers were assigned to write a lesson plan, they requested that each teacher in the class sign up for a different topic so that they could then have a set of lesson plans at the end of the course that would reflect the breadth of topics taught in the course. This decision had an impact on the extent to which the teachers' lessons were implemented in their classrooms. While in theory it may seem like a good idea for the class of teachers to create lesson plans or *PowerPoint* lectures or virtual field trips that span the entire set of course topics, this decision needs to be reconsidered. From observations during follow-up sessions and interviews with teachers, too many of the teachers in the courses were teaching in school divisions where they were not able to choose the time of year that they would be able to teach topics in their curriculum. As a result, teachers were bringing to the follow-up sessions lesson plans that they had not taught or might not ever teach. Even teachers teaching biology can document the ways in which they tie astronomy, geology, meteorology, and oceanography curricula into their daily instruction. We encourage content faculty to require that their participating teachers bring in documentation and lesson plans that they have already used to teach their students, along with at least three samples of student work. This way, the teachers have an opportunity to have a practicing earth scientist examine their lesson planning efforts and their students' work in terms of content structure and accuracy. For example, when the teachers presented their lesson plans to the rest of the teachers enrolled in the class, direct observation of follow-up sessions revealed that earth science co-instructors would frequently comment and make suggestions for teachers to consider in terms of content accuracy. Occasionally, re-teaching was needed and performed by one or both co-instructors, usually the science content faculty member. Verifying accuracy or clarifying nuances is an important role for scientists to play in teacher development. As content specialists, earth scientists are in a unique position to provide guidance to teachers on how to improve their lessons so that they can teach more effectively and their students can learn more efficiently.

Continued Content Preparation: Making Content Meaningful

Not only do the standards for earth science classroom instruction identify the necessity for presenting science concepts in a real-world context, but research on student motivation indicates that students learn more efficiently when they are exposed to exciting, real-world applications of what they are learning—when the science they are learning feels real and relevant to them [13]. As content specialists, earth scientists are at the forefront of keeping tabs on new and exciting findings within their field. Direct observation of follow-up sessions revealed that content faculty used follow-up sessions for further content knowledge, but the emphasis was more on real-world application as opposed to foundational understanding. In a follow-up session, one earth science content faculty member made a presentation on the landfalls of Hurricanes Katrina and Rita only weeks after they occurred in 2005, and included information on oceanography, weather conditions of the storms, and the coastal geology of Louisiana. Afterward, informal interviews with teachers revealed their appreciation of the instructor's content knowledge expertise and ability to teach them about current weather-related events in such a thrilling manner that it invoked their own sense of awe and wonder. Learning about events as they occur or are being uncovered brings an excitement to learners regardless of age. Interviews with teachers revealed that they were inspired by this experience and intended to work toward creating this same level of excitement among their own students.

"School Science" versus "Real Science"

Since the earth science curriculum is so broad (geology, astronomy, oceanography, and meteorology), interviews revealed that among the middle and high school earth science teachers in this study, the teachers were weak in at least one area of their curriculum. Faced with this weakness, teachers learn only the bare minimum of the content in this area before they teach it to students. Worse, they may only have time to grab the students' textbook and read it before they have to talk about it in class. Sometimes the only earth science resources available to teachers at the middle and high school levels are lacking in content accuracy; i.e., ideas have become so simplified during the "watering down" process that they are no longer accurate. A review of lesson plans and laboratory activity sheets submitted and shared during follow-up sessions revealed several such inaccuracies. The co-instructors addressed these as they came up during the follow-up sessions. Additionally, teachers may not have an adequate understanding of how practicing earth scientists actually use the information they are trying to teach their students. As a result, the content gets presented in a way that does not reflect the nature of the earth science discipline and therefore, it becomes inaccurate. In an interview with one content faculty member serving as co-instructor for an astronomy course for teachers, the instructor revealed that follow-up sessions provide an opportunity to assist teachers in presenting science in the classroom that is more representative of how it is used by practicing astronomers. An example cited by the instructor relates to the phases of the moon. The instructor explained that students may learn the phases of the moon out of order because the teacher fails to understand the underlying scientific principles. The teacher is merely doing what the *Standards of Learning* has mandated: teach the students the phases of the moon. Beyond memorizing information, knowledge of the processes that cause the apparent changes in the phases of the moon is necessary for teachers and students to achieve real understanding.

Positive Impact of Experienced Earth Science Teacher as Co-Instructor

Each of the courses included in this study included an experienced earth science teacher as co-instructor in addition to a university scientist. One co-instructor explained that the role is to ensure that the activities of the course are relevant to the lives, interests, and needs of teachers enrolled in the courses. In an age of high-stakes testing, the co-instructor with expertise in K-12 teaching understands first hand how important it is for professional development experiences to be directly translatable into classroom practice. During both the summer and follow-up sessions, the K-12 co-instructor is in a position to present the ways in which science content can be reshaped, reformulated, and flipped upside down to create meaningful, standards-based learning experiences for students. During follow-up sessions, the high school earth science teacher co-teaching with *Geology* and *Oceanography* content faculty was observed performing demonstrations that the teachers could easily conduct in their own classrooms to illustrate an abstract science concept. Relying on their teaching experience, the K-12 co-instructor was able to identify ways in which middle and high school students could potentially become confused by content. These alternative conceptions were explored so that the teachers in the class would be better prepared to prevent and/or address alternative conceptions in their own classroom. The K-12 co-instructor's role in the courses was frequently cited by the teacher participants as one of the most effective components of the professional development program.

Implications for Future Earth Science Teacher Professional Development

Follow-up sessions provide an ideal means for stakeholders to determine the extent to which professional development for teachers positively impacts the teachers' classrooms and their students' achievement. Findings from this study illustrated how follow-up sessions can provide support for teachers to extend what they learned from professional development training, but the follow-up assignments and activities must be carefully planned to provide meaningful, continued learning opportunities for teachers. To truly make a difference on student achievement, the findings from these follow-up sessions reveal that these sessions need to do the following: provide an opportunity for teachers to share and discuss with co-instructors and fellow teachers enrolled in the course what they implemented in their teaching from the summer; examine with their teaching peers and co-instructors the scientific accuracy of their products and how these support their students' learning; and, critically analyze their students' work in order to inform their own future planning and teaching efforts. ■

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