Kentucky Journal of Excellence in College Teaching and Learning

Volume 10 Article 6

January 2013

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Steven Kerlin
Northern Kentucky University

Kentucky Journal of Excellence in College Teaching and Learning 74
Volume 10, November 2012

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Steven Kerlin, Northern Kentucky University

Abstract

The recently released Framework for K-12 Science Education (National Research Council, 2012) calls for science education to addresses weaknesses in current science education of unorganized learning progressions, a focus on a breadth of discrete facts, and a lack of experiences in how science is actually done. Teacher professional development in inquiry science teaching and learning is one way to address these current issues in science education effectively. Higher education faculty have been one of the major groups of providers of teacher professional development programs. Many of these professional development programs have been delivered in short-term workshops and traditionally focused on increasing teacher content or learning new lesson ideas. As such, these programs have achieved limited successes in creating substantive changes and improvements in K-12 science teaching and learning. The research presented describes features of science teacher professional development that promote the adoption of inquiry-based K-12 science teaching and learning. Education and science faculty collaborated on this project to design and implement a professional development model for practicing science teachers. Sustained professional development enhanced by an immersive field study encouraged experienced teachers to modify their instruction to include scientific inquiry strategies that challenged their students to manipulate and make sense of actual scientific data. Three case studies and end of program feedback are described along with implications for other professional development programs.

Keywords: Professional development, experienced teachers, science inquiry, teaching, and learning

Introduction

Many Science, Technology, Engineering, and Mathematics (STEM) faculty collaborate with their education department colleagues to plan and deliver teacher professional development (PD) outreach activities. These activities typically utilize methods designed to increase STEM content knowledge or introduce new activities or instructional strategies. The PD model described here employed other methods with the goal of increasing in-service science teachers' use of inquiry-based instruction.

The model included immersing experienced science teachers in the inquiry methods of scientists through ecological field studies, examples of inquiry instruction, formation of a common understanding of inquiry, and sustained collaborative training. Examples of how science inquiry teaching and learning were then implemented in middle and high school classrooms are provided, along with the program evaluation and a description of specific features of the PD model that can be replicated in other settings.

Many experienced science teachers are often resistant to change their instructional techniques to include more inquiry teaching practices even though inquiry-based teaching is strongly recommended by science education reform documents (American Association for the Advancement of Science, 1993; National Research Council [NRC], 1996, 2000, 2012).

These documents encourage teachers, through research findings and classroom examples, to implement more inquiry-based strategies in problem-solving contexts and spend less time presenting content through direct instruction. The recently released Framework for K-12 Science Education (NRC, 2012) addresses weaknesses in current STEM education of unorganized learning progressions, a focus on a breadth of discrete facts, and a lack of experiences in how science is actually done. This new framework recommends science education be built around three major dimensions of scientific and engineering practices, crosscutting concepts that unify science and engineering fields, and core disciplinary ideas. Science education should no longer focus on content knowledge but also engage students in scientific practices and apply knowledge across contexts.

Teachers face external barriers and internal dilemmas that punctuate their resistance to change instruction to more inquiry-based practices. For example, recent political pressures associated with high-stakes standardized testing has led to instruction centered on preparation for the tests. Internal personal dilemmas include fear of relinquishing some control to students and a naïve conception of inquiry-based teaching and learning strategies. Addressing teachers' understandings of science as inquiry and learning as inquiry are critical to the promotion of inquiry teaching (Anderson, 2002). Professional development that addresses these issues is needed to help practicing science teachers implement more inquiry-based teaching strategies.

Today's high stakes testing, along with state and school district accountability measures, place pressures on science teachers to prepare their students to perform well on standardized tests. Many teachers therefore feel they must focus their instruction on content knowledge and the ability of their students to answer multiple-choice questions. In many cases, this approach leads to direct instruction instead of critical inquiry-based teaching. However, understanding science is more than knowing facts (Bransford, Brown, and Cocking 1999).

The emphasis of science education research has been on learning for understanding, which means having the ability to apply knowledge to novel situations. Uses of inquiry-based teaching methods help students not only acquire concept knowledge but also skills and abilities of doing science along with understandings about the process of scientific inquiry (National Research Council, 2000). In the case of standardized tests, students with more complete understandings of science content and processes will be able to apply knowledge to questions that provide scientific data and ask students to make sense of those data. These types of questions are increasingly used on standardized tests.

Moving from direct instruction to student-centered instruction, which includes giving students some control of their learning, may be frightening for science teachers. Many teachers believe this transition requires advanced science content knowledge in order to be able to answer all of the students' possible questions and explain all possible experimental outcomes. Science teachers have long used "cookbook" labs as crutches to address this fear. Cookbook labs are science activities that include simplified or manipulated scientific data that lead learners to one correct conclusion. Recent studies have shown that students are capable of understanding raw scientific data from first-hand and second-hand sources (Hug & McNeill, 2008).

Teachers can move beyond the use of simplified data provided in textbooks and other curricula to challenge students to make sense of actual scientific data collected in their local environments or provided by scientific sources such as the United States Geological Survey, National Oceanographic and Atmospheric Administration, or regional biological field stations.

Students have the ability to sort through these types of data sources to construct scientific claims and justify them with appropriate evidence (Kerlin, McDonald, & Kelly, 2010). The process of using actual scientific data helps elicit multiple claims, misconceptions, and more closely resembles the practices of actual scientific inquiry. Further, the use of data collected locally can provide greater relevancy and meaning to both teachers and their students.

Next, teachers need to develop a shared common understanding about science inquiry teaching and learning. Without this shared understanding of scientific inquiry, teachers are unlikely to develop and enact inquiry lessons suggested by educational reform (Duschl & Grandy, 2008). In spite of the ubiquitous use of the term inquiry, many questions remain for teachers. What does it mean to teach science as inquiry or through an inquiry approach? Is it an approach that can be realized or is it more theoretical (Anderson, 2002)?

One common misconception of inquiry teaching is that it is an all-or-nothing approach. Inquiry investigations should be included as teaching methods to address the issue of a “mile wide and an inch deep” curriculum. Inquiry investigations enable students and teachers to dive deeper into particular scientific phenomena and practice scientific thinking. However, a complete switch to the use of open-inquiry investigations is also not appropriate, as it would remove teachers as instructional guides in the classroom.

Open-inquiry is more akin to the work of actual scientists. K-12 science teachers still need to maintain structure in the classroom to move learning toward required standards but should do this in the manner of a guide not a lecturer. Unstructured activities do not help students develop conceptual frameworks. Instead, carefully sequenced scientific questions and learning guided by the teacher is needed to help students critically think about scientific concepts (McDermott & DeWater, 2000).

A commonly accepted characterization of classroom science inquiry is described in Inquiry and the National Science Education Standards (NRC, 2000). This publication lists the essential features of classroom inquiry (p. 25).

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations.

These essential features of inquiry clearly focus learning on scientifically oriented questions, student engagement with evidence (data), and communication of explanations. The idea that inquiry is not commonly or consistently used (Bybee, 2000) may be overcome by professional development that formulates a common understanding of classroom inquiry as described in this

NRC publication and immersive scientific inquiry experiences for teachers.

To promote meaningful change in science teaching, PD programs must prepare teachers to try new activities in their classrooms. In this process teachers become teacher-learners in which they are aware of the process of change and development (Hewson, 2007) while realizing the fact that change is not instantaneous. The process of changing teaching strategies to include inquiry is a progression that requires sustained development. "Radical changes to teaching practices rarely occur" (Guskey, 2002 in Grove, Dixon & Pop, 2009). This commonly accepted research finding illustrates to PD providers that short-term teacher workshops are not effective in bringing about actual change in classroom practice. One-day or even one-week stand-alone workshops may excite teachers about content or teaching strategies but items learned are quickly forgotten and rarely implemented in the classroom.

An example of a more intensive PD program that immerses teachers in the practices of scientific inquiry is the National Science Foundation (NSF) Research Experiences for Teachers (RET). RET programs typically place teachers in a university or industry laboratory for six to eight weeks during the summer. Participation in these authentic science research experiences gives teachers a glimpse of the real world of scientific research (Grove et al., 2009). The goals of the NSF program are to build long-term relationships between K-12 STEM teachers, college faculty, and the NSF research community and help teachers translate their experiences and new science and engineering content knowledge into classroom activities (NSF, 2012).

In one study of an RET program, Grove et al. (2009) expected teachers to implement new science teaching strategies aligned with the concepts they studied in their research experiences but found only small subtle changes to teaching practice. Changes were not illustrated in lesson plans but changes in the theme of inquiry were noticed in the way teachers questioned students as evidenced in case studies using research data from observations and interviews.

In another study of a marine ecology RET by Blanchard, Southerland & Granger (2009) teachers gained an understanding of scientific inquiry from their direct research experiences. However, even with this direct research experience combined with reflection and training in a clear model of scientific inquiry there were still impediments to teacher change. Differences in teachers' plans to include more inquiry-based teaching were not attributed to the RET program but to rethinking of teaching to understand the theory of inquiry and student learning prior to the RET experience (Blanchard et al., 2009).

These examples illustrate that immersive scientific inquiry experiences alone do not lead to substantive changes in classroom practice. PD programs must include additional supports and teachers must be motivated to rethink their practice. Additionally, immersive RET programs are only available for small number of science teachers across the United States.

A sustained PD program or series of programs that promote science inquiry is needed to bring about substantive changes in instructional practice. Outlined below is a description on one such program followed by recommendations of PD features for consideration in planning science teacher professional development that promotes inquiry teaching and learning that has the potential for widespread implementation.

Context

Eight practicing middle and high school science teachers participated in a yearlong PD experience and research study sponsored by an Improving Educational Quality grant from the Kentucky Council on Postsecondary Education. The main objective was to encourage these in-service science teachers to increase the use of science inquiry teaching strategies and actual scientific data in their instruction.

The teachers represented urban, suburban, and rural school districts within and near a metropolitan region with diverse students, in terms of socioeconomic status and ethnicity. Students represented a spectrum of traditionally high and low achievement on standardized tests. The instructors and researchers were university professors of science education, science, educational psychology, and mathematics education.

The PD model included a 2-week intensive workshop during the summer of 2009, three daylong follow-up workshops spread throughout the 2009-2010 school year, and a minimum of three classroom visits by an instructor for each teacher. Many of the teachers participated in additional conversations and collaborations with the university instructors. Activities in the summer and follow-up workshops focused on building a common understanding of science inquiry teaching and learning in K-12 education and immersing teachers in actual science inquiry practices. Each teacher, with assistance of science or science education faculty, devised an individual action plan at the end of the summer immersion workshop.

The workshops included the following sessions: a video example of a seismology inquiry lesson (Kerlin, McDonald & Kelly, 2009; 2010) and discussion of an example inquiry-based unit; research-based literature of inquiry teaching; discussions of scientific learning communities, student use of evidence to form scientific claims and a framework for student use of data as evidence.

In addition, they included a sample inquiry activity of analysis a photomosaic of the biological distribution in a deep-sea hydrothermal vent environment with an unknown scientific conclusion; content knowledge about the ecology of the local Ohio River basin; an ecosystem assessment, experimental design and data gathering of water quality parameters; curriculum planning that included local river quality data, and development of teacher action plans for implementation.

Particularly important components of the PD experience were the activities that immersed teachers in an experiment to determine the health of the local section of the Ohio River and tributaries. The teachers were involved in all aspects of the study, including the design, methods, data collection, and data analysis. This activity included a field study at a Biology Field Station on the Ohio River and a session at one of the follow-up workshops to make sense of historical river quality data. During the field study teachers used scientific instruments to gather data following protocols in the same manner as research scientists. They were then challenged to make sense of their small sample of data to form a conclusion about the health of the river during this snapshot investigation.

Later at the follow-up workshop teachers were provided with a larger set of historical data and further challenged to recognize correlations between the water quality parameters and to form scientific conclusions about the health of the river over an extended time. Full-scale RET-like scientific research programs mentioned earlier are not possible for large numbers of science teachers. The focused summer field study combined with the follow-up historical data analysis and additional inquiry activity examples provided similar immersive science experiences but is more akin to scientific studies that teachers can guide their students through.

Classroom visits provided the opportunity for the university science education and science professors to work directly with the in-service science teachers. University faculty were able to assist teachers with instructional planning decisions, resources, enactment of lessons, and provided feedback based on classroom observations. In this manner, individual attention was given to each teacher to help him or her work toward the enactment of their individual action plans for improving education in their classrooms.

Research Methods

Qualitative research data were collected during and after implementation of the yearlong PD experience. Researchers conducted observations of classroom teaching and collected ethnographic field notes during those visits. Observations were used to verify the enactment of science inquiry teaching and learning. Field notes were then analyzed for emergent themes (Emerson, Fretz & Shaw, 1995). Additional qualitative data was gathered from teachers during and after the school year in the form of accounts of their teaching practices. Analysis of field notes along with feedback from teachers during the summer workshop and school year also served as formative assessment in an action research framework that enabled the instructors and researchers to design follow-up workshops and individual mentoring to enrich the learning experience of the teachers.

An external evaluator also designed and administered a year-end survey. The teachers responded to Likert scale survey questions and provided open-ended feedback. Given the small sample size, eight science teachers, the results were analyzed for gain and standard error according to a before and after rating.

Case studies (Merriam, 1998) of diverse set of three of the teachers are presented as the main way to illustrate change in teacher instruction that included more science inquiry and use of actual scientific data. The following three examples are presented because they show how three different experienced teachers identified specific deficiencies in their instruction and approached the task of improving their instruction by implementing science inquiry strategies.

Results

Emergent Themes. Thematic analysis of field-notes and teacher feedback during the workshops, via email and other solicited accounts of teaching practice revealed initial fears of change of instructional approach, access to actual scientific data, and in some cases confidence in understanding the science. Examples and sustained support were needed to encourage and facilitate increased use of science inquiry teaching strategies and use of actual scientific data. An overarching theme that emerged was that teachers were at first reluctant to move from teacher-directed classrooms to a guided inquiry approach. As the teachers became more comfortable with guided inquiry through the PD activities, discussions, and classroom supports they were able to begin to modify their instructional approaches and realize the benefits to student learning. Three case studies demonstrate the impact of the PD program.

Case study 1 - Mrs. Holly – High School Chemistry, High Achieving Suburban School. Mrs. Holly's goal was to introduce students to the inquiry method, to practice observing, formulating, and testing hypotheses, and learn science concepts such as types of chemical reactions, energy relationships of metallic ions, and evidence for atomic structure in line spectra. Her approach was to include inquiry based laboratory experiments in her instruction.

She searched for and modified investigative labs that engaged her students in scientific investigations that moved the structure of the class from teacher directed to guided inquiry. Students had the freedom and responsibility in these labs to make a number of procedural decisions, collect data, analyze the data to make a scientific argument based on evidence and communicate their explanations in a large group post-lab discussion. Mrs. Holly helped guide the students throughout their experiments and guided the concluding discussions to reach accepted conceptual understandings. By focusing on guided laboratories Mrs. Holly was able to encourage her students to practice scientific inquiry methods and think critically about chemistry.

Case study 2 - Mrs. Good – High School Biology, Average Achieving Rural School. Mrs. Good's goal was to engage her students in scientific thinking about actual scientific data. She challenged her students to interpret scientific data to make evidence-based claims from data analysis and the use of scientific inquiry skills. Two examples of activities that she designed for her students focused on greenhouse gases and enzyme reaction rates. Students were provided with actual CO_2 concentration data, in the form of graphs, gathered at the Mauna Loa Observatory and the Department of Meteorology and Physical Oceanography at the University of Miami. Students were prompted to analyze the data and form scientific explanations about global temperature.

In a second example Mrs. Good provided students with graphical data about enzyme reaction rate compared to temperature. She gathered the data from the Association for Science Education in the United Kingdom and the Food and Agricultural Organization of the United Nations document repository. Mrs. Goode was able to use open source Internet scientific data to provoke scientific thinking in her students and challenge them to critically analyze actual scientific data.

Case study 3 - Mrs. Cook – Middle School Integrated Science, Lower Achieving Urban School. Mrs. Cook implemented a redesigned instructional unit on the rock cycle using a guided inquiry approach. The former unit was primarily teacher delivered content using a direct instruction approach followed by a handful of activities. The redesigned unit engaged students in guided inquiry activities such as the Journey through the Rock Cycle and an online interactive rock cycle model at the beginning of the unit.

Content knowledge was infused in these and subsequent activities. In this approach the students generated more scientific vocabulary than the former teacher directed approach. Mrs. Cook noted that student questioning and motivation to learn increased. The redesigned unit and guided inquiry approach also allowed students to "own" their learning and make choices while creating [cognitive] "discomfort" for students to "think" their way through.

Year-end survey and responses. The following data were collected and analyzed by the external evaluator from the entire population of teachers in the PD program. All eight science teacher participants responded to the questions in Table 1 on a 5-point Likert scale. Table 2 lists additional year-end comments from teachers and conclusions from the external evaluator.

Table 1. Year-end survey results on science strategies:

Question	**Before**	**After**	**Gain (Std.Err)**
To what extent do you use inquiry strategies in your instruction?	3.1	4.1	1.0 (0.3)
To what extent do you engage your students in discussions of their evidence based scientific claims?	3.0	4.0	1.0 (0.3)
To what extent do you engage your students in hands-on data collection and reporting?	3.3	3.9	0.6 (0.3)
To what extent do you engage your students in data interpretation from charts, tables and graphs?	3.4	4.5	1.1 (0.2)
To what extent do you have your students compare or combine data from a simple data presentation (e.g. sum data from a table)?	2.6	3.8	1.1 (0.3)
To what extent do you utilize online collaboration tools in your instruction?	2.0	3.3	1.3 (0.4)
To what extent do you utilize other online resources in your instruction?	3.4	4.5	1.1 (0.4)
Overall Average for Science Training	**3.0**	**4.0**	**1.0 (0.3)**

Table 2. Additional responses provided by teachers in open feedback and conclusions from external evaluator.

Direct teacher feedback provided to external evaluator
"We have developed a partnership [with the instructors] that will continue after this project."
"Whenever they came to visit I felt like I learned more in the time they were there than at any other time during school."
Conclusions from the external evaluator
In terms of the lasting impact, respondents indicated that they had made lasting connections with other educators (3 teachers), had changed the way they thought about students as whole persons (3 teachers), had greatly improved their teaching practice in general (3 teachers), or had begun to use a more active or inquiry-based mode of instruction (3 teachers).
Overall, the teachers indicated they had "very much" increased their use of instructional strategies that elicit higher order thinking skills (mean 4.3 / 5, with std. error = 0.2). It should be noted that this outcome was a primary motivation for initially seeking grant funding.
Although no reliable data are available for measuring the impact on student achievement, it is clear from the year-end surveys that the teachers gained a great deal. They clearly appreciated the opportunity and value the connections they have made with their colleagues. They also report having learned a great deal about effective motivational strategies, how to enact inquiry-based science strategies, and incorporate mathematics strategies that deepen understanding.

Findings by the external evaluator showed that the PD program was effective in promoting changes in in-service teachers' instructional practices to include more inquiry-based instruction. In addition to the evaluation of the PD program, ethnographic research of field notes and case studies illustrate specific changes in instructional methods because of the PD model. Given these evaluation and research findings a set a critical features of the PD model has been identified that may be implemented in other settings to generate similar outcomes.

Conclusions and Implications

This study demonstrates that it is possible for experienced teachers to update their teaching strategies and approaches to include science inquiry methods. Moving to inquiry methods does not require a complete overhaul of instruction. Small changes that result in big differences can be integrated with pre-existing instructional methods.

Science teachers in the PD program moved away from cookbook lab activities and teacher direct instruction to engaging students in inquiry based activities. In this research, changes were specifically illustrated through three individual case studies and action plans: incorporation of inquiry based labs, use of actual scientific data that challenged students to analyze data and make scientific claims, and the redesign of an existing unit by changing the sequence of activities to create utilize an inquiry approach that increased student questioning.

Contrary to cookbook lab activities, students in these classrooms were given freedom to investigate and analyze data to form scientific explanations based on evidence. Students then communicated their explanations to their peers and the teachers. These actions demonstrated that the science teachers gained an understanding of science inquiry teaching and learning, implemented corresponding changes to their instruction, and challenged and guided their students to think critically about scientific processes and concepts in a similar manner to research scientists.

Below is a list of five features of the PD program that were critical to the process of promoting inquiry science teaching and learning. These features may be helpful in other PD contexts as they can be viewed as a foundation for the development of science inquiry PD.

- Collaboration of STEM and education faculty with teacher participants to plan and conduct PD programs.
- Sustained PD support in the classroom and linked follow-up workshop experiences.
- Modeling examples of inquiry lessons.
- Immersion in an authentic scientific research experience.
- Development and individualized support of science teacher PD action plans.

Collaboration of teachers with peers and experts is a key facet to helping teachers use inquiry-based instructional methods (Blumenfeld, Krajcik, Marx & Soloway, 1994; Anderson, 1996). Collaboration provides an important context for the re-assessment of internal educational values and beliefs through reflection of actual classroom experiences (Anderson, 1996; 2002). In the context of the study presented here collaboration was purposely planned. Education and science faculty worked together to plan and implement the initial summer PD sessions

Collaboration of STEM and education faculty is not new but should be expanded to include the teacher participants. Teacher participants in this study context became integral contributors to the selection of follow-up workshop session topics throughout the year and the design of their individual PD action plans. In this capacity the team of teachers and university faculty collaborated to address common and individual PD needs of the in-service science teachers.

As described more extensively in the introduction of this paper, sustained professional development programs are needed to create meaningful change in classroom practice. Follow-up workshops throughout an academic school year, along with classroom visits, promoted success in the PD program described in this study. Classroom visits took the form of co-planning, co-

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teaching, and/or collection of observational field notes followed by feedback.

Prominent features of the intensive 2-week summer workshop and follow-up workshops were sessions that modeled examples of inquiry lessons, the development of a common understanding of science inquiry teaching and learning, and immersion in a brief authentic scientific research experience. Sessions that modeled inquiry lessons were placed teachers in the roles of students. This approach gives teachers first-hand experiences in the challenges and cognitive dissonance that inquiry lessons include. In addition, participating in inquiry lessons as students can be used to model how an instructor can guide discussions through questioning that encourages students to form scientific conclusions based on evidence. The elevated importance of directing student attention to evidence is demonstrated in the model inquiry lessons then reinforced in subsequent discussions that were used to develop a common understanding of inquiry. This understanding of inquiry is based on extensive research in science inquiry teaching and learning and applied to direct examples from the model lessons.

Another prominent feature of the workshop experiences was immersion of teachers in authentic scientific research. Anderson (2003 in Blanchard et al., 2009) argues that teachers' lack of experiences with authentic scientific inquiry gives them a static or authoritative view of how the world works. This authoritative view of science translates directly into teaching practice and leads to didactic instructional methods. Sustained authentic scientific inquiry experiences, such as RETs, are not available to all science teachers. Moreover, RET or similar experiences by themselves have been shown to have minimal or subtle impact toward changing teaching practice, as mentioned in research cited earlier.

Shorter duration but still authentic science inquiry experiences in the research context presented in this paper proved helpful to promote a complex understanding of science inquiry practices and thinking that translated to changes in classroom practice. In this sense, authentic scientific experiences are seen as one of the necessary features of PD programs to promote inquiry-based teaching.

In the context of this PD program the authentic research experience focused on the water quality and ecology of the Ohio River Basin. Field study experiences and access to large amounts of historical scientific data were possible because of the inclusion of a research biologist as a collaborative partner in the planning an execution of the yearlong PD experience. Field research experiences were possible by the use of a local biological field station facility. Such facilities immerse teachers and students alike in the process of science and serve as local outdoor classrooms and laboratories.

The instructors in the PD program presented as the context of this research continue to successfully use this facility and other local natural environments along with scientific data collected at this and other research field stations in ongoing PD programs. A guide to Kentucky Field Stations and natural areas for scientific research can be found in Richter, St. Andre, White, & Wilder (2010). Information about additional natural areas and research field stations across the U.S. can be found at the Organization of Biological

Field Stations and the National Ecological Observatory Network.

These organizations are just two examples that provide access to possible sites for authentic field studies and have extensive amounts of scientific data that can be classroom inquiry-based activities and discussions for science teacher PD programs and K-12 education. Other local natural areas such as county parks and scout camps have also been found to be effective locations for immersive scientific research experiences in other teacher PD programs.

The last important feature of a PD program to promote inquiry science teaching and learning is the development and use of individual PD action plans. Experienced science teachers arrive at PD programs with different levels of comfort, experience, and understandings of science inquiry teaching. Science teachers work in varied school contexts with a range of affordances and pressures from school administrations, parents, and students that desire high student academic performance. The research presented showed that science PD programs that have the goal of changing classroom instructional practice, in this case to promote the use of science inquiry teaching methods, must include and individualized component. The use of individual PD action plans helps personalize the PD experience to address individual needs and can help shape the long-term PD experiences by providing the ability to recognize teachers' struggles and address them during follow-up workshops and classroom visits.

The study presented in this paper has described the success of one example of a yearlong teacher PD program in promoting science inquiry teaching and learning. Research results from case studies, observations, and end of program feedback were examined to identify prominent features of the PD program that lead to teacher implementation of inquiry-based teaching strategies. As illustrated in the Framework for K-12 Science Education (NRC, 2012), there is a critical need for a change in science teaching practices to address the shortcomings of current student achievement in science knowledge and skills.

Inquiry based teaching methods adopted by the science teachers in this study tackled these shortcomings by challenging students to engage in scientific practices, analyze actual scientific data, and formulate scientific questions and explanations. The PD features to promote inquiry science teaching and learning proved successful in this study context in creating changes in teacher instruction that included more inquiry based methods. These features should be considered in the planning and development of other science education PD programs.

References

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy.* New York: Oxford University Press.

Anderson, R.D., (1996). *Study of Curriculum Reform*. Washington, DC: U.S. Government Printing Office.

Anderson, R.D., (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1-12.

Blanchard, M.R., Southerland, S.A., & Granger, E.M. (2009). No silver bullet for inquiry: Making sense of teacher change following an inquiry-based research experience for teachers. *Science Education, 93* (2), 322-360.

Blumenfeld, P.C., Krajcik, J.S., Marx, R.W., & Soloway, E. (1994). Lessons learned: How collaboration helped middle grade science teachers learn project-based instruction. *The Elementary School Journal, 94*(5), 539-551.

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

Bybee, R.W. (2000). Teaching science as inquiry. In J. Minstrell & E. van. Zee (Eds.), *Inquiring into Inquiry Learning and Teaching in Science* (20-46). Washington, D.C.: American Association for the Advancement of Science.

Duschl, R., & Grandy, R. (Eds.). (2008). *Teaching Scientific Inquiry: Recommendations for Research and Implementation.* Rotterdam: Sense Publishers.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (1995). *Writing Ethnographic Fieldnotes*. Chicago & London: The University of Chicago Press.

Grove, C.M., Dixon, P.J., & Pop, M.M. (2009). Research experiences for teachers: Influences related to expectancy and value of changes to practice in the American classroom. *Professional Development in Education, 35*(2), 247-260.

Hewson, P.W. (2007). Teacher professional development in science. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (1179-1203). Mahway, New Jersey: Lawrence Erlbaum Associates.

Hug, B. & McNeill, K. L. (2008). Use of first-hand and second-hand data in science: Does data type influence classroom conversations? *International Journal of Science Education, 30*(13), 1725-1751.

Kerlin, S., McDonald, S., Kelly, G. (2009). Mapping a science inquiry unit. *Journal of Classroom Interaction*, 43(2), 4-13.

Kerlin, S., McDonald, S., & Kelly, G. (2010). Complexity of secondary scientific data sources and students' argumentative discourse. *International Journal of Science Education, 32*(9), 1-19.

McDermott, L.C., & DeWater, L.S. (2000). The need for special science courses for teachers: Two perspectives. In J. Minstrell & E. van Zee (Eds.), *Inquiring into* *inquiry learning and teaching in science* (241-257). Washington, DC: American Association for the Advancement of Science.

Merriam, S.B. (1998). *Qualitative Research and Case Study Applications in Education.* San Francisco, CA: Jossey-Bass Publishers.

National Research Council. (1996). *National Science Education Standards.* Washington, D.C.: National Academy Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards.* Washington, D.C.: National Academy Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press.

National Science Foundation. (2012). *Research experiences for teachers (RET) in engineering and computer science.* Retrieved from http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5736

Richter, S., St. Andre, C., White, D., Wilder, M. (2010). A field guide to Kentucky field stations available for education and research. *Journal of the Kentucky Academy of Science, 71*(1-2), 95-2010.

Steven Kerlin is Assistant Professor of Science Education, and Director of the Center for Environmental Education, Northern Kentucky University.