National Center for Research on Rural Education (R²Ed)

A Case Study of Coaching in Science, Technology, Engineering, and Math Professional Development

Sue Ellen DeChenne, Gwen Nugent, Gina Kunz, Linlin Luo, Brandi Berry,

Katherine Craven, and April Riggs

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University of Nebraska Lincoln

Abstract

A professional development experience for science and mathematics teachers that included coaches was provided for ten science and math teachers. This professional development experience had the teachers develop a lesson that utilized the engineering context to teach a science or mathematics concept through guided inquiry as an instructional methodology. Developing a guided inquiry lesson can be a difficult task for teachers. Science teachers have inquiry standards that they must meet and research indicates that teaching through guided inquiry is an effective method of teaching science content. Mathematics teachers are being asked to incorporate more active and cooperative instructional experiences in in their classrooms. Results of the professional development experience indicate that all but one of the teachers were successful in developing and implementing guided inquiry lessons within their classrooms. Matching coach and teacher by content area was found to be important. Coaches provided help to the teachers in developing their lessons by providing a sounding board for teacher ideas, offering suggestions for the lessons, observing and providing feedback, and helping the teachers understand guided inquiry.

Introduction

Science and math teachers have increasing demands placed on them, including integration of technology and engineering into their curriculums (Anderson-Rowland, et al., 2002; National Research Council, 2011). Many of these teachers lack content knowledge and are unprepared to teach engineering and technology (ASEE, 2004; McCuen & Yohe, 1997). Additionally, despite the emphasis on the development of inquiry skills in the science teaching standards and reform movements, many science teachers do not know how to successfully teach inquiry (Anderson & Michener, 1994; Bybee & Fuchs, 2006). Translating scientific inquiry into effective classroom instruction can be a demanding task, requiring both discipline-based inquiry content knowledge and skills in inquiry teaching. Professional development can improve teachers' understanding of engineering content (Nugent, Kunz, Rilett, & Jones, 2010; Poole, deGrazia, & Sullivan, 2001; Zarske, Sullivan, Carlson, & Yowel, 2004) and their knowledge of inquiry and skills in inquiry teaching (Haney, Wang, Keil, & Zoffel, 2007; Vanosdall, Klentschy, Hedges, & Weisbaum, 2007).

Unfortunately, Cornett and Knight (2009) indicate that teachers successfully implement new teaching strategies learned in the most common professional development format – a summer workshop – only about 15% of the time. However, if the professional development is followed by instructional coaching in the newly acquired teaching strategy at the teacher's school, successful implementation reaches 85%. Coaches are fairly common in literacy and mathematics, but instructional coaching in science is currently rare (Kraus, 2008). However, the addition of instructional coaches to a summer science, technology, engineering, and mathematics (STEM) professional development experience should also provide increased learning of engineering and inquiry content and implementation of inquiry teaching strategies.

Research Questions

1. What are important aspects of the STEM professional development?
2. What are important aspects of the coach and coaching process?
3. How does this STEM professional development affect the participants' (i.e., teachers, coaches, and students) understanding of and beliefs about inquiry and engineering?

Literature Review

Science Inquiry

The national science standards acknowledge that science inquiry is multifaceted. In fact, in science education there are at least three main applications of science inquiry: content, set of student process skills, and as an instructional methodology. Science inquiry as content includes understanding of the nature of science and the scientific process as used by scientists (Anderson, 2002).

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, pg. 23)

There are five essential inquiry process skills that students should learn: "Learner engages in scientifically oriented questions. Learner gives priority to evidence in responding to questions. Learner formulates explanations from evidence. Learner connects explanations to scientific knowledge. Learner communicates and justifies explanations" (National Research Council, 2000, pg. 25). To learn these essential inquiry process skills, the students need a lot of scaffolding in scientific experimentation, from the broad ideas such as "What is a testable question?" or "How to formulate a hypothesis?," to the smaller details, including "What controls are applicable to this experiment?" and "What is the best way to present my results?"

Finally, science inquiry can also be an instructional methodology; however, it is not one methodology but a continuum of instruction from directed experimentation to open discovery. A prescribed experiment in which the outcome is known and the students are confirming something they have been taught is a very different teaching and learning experience from an experiment where the question and the methods are student generated (i.e., a science fair project). Inquiry instruction can fall all along this continuum.

Because of this broad range of types of inquiry implementation, determining the overall effect of inquiry instruction on student achievement and learning goals has been difficult. Meta-analyses on the effects of inquiry-based instruction in kindergarten to college over a 50 year time span have generally found more positive effects for inquiry instruction. A group of meta-analyses, published in 1983, showed effect sizes for inquiry instruction (broadly defined) on student outcomes of 0.32 (Wise & Okey, 1983), 0.35 (Bredderman, 1983), and .43 (Shymansky, Kyle, & Alport, 1983). Schroeder, Scott, Tolson, Huang, and Lee (2007) found the effect size for inquiry instruction on student outcomes, since Wise and Okey, was .65. In a quantitative and qualitative meta-analysis of inquiry instruction, Minner, Levy and Century (2010) found that 51% of the research showed a positive impact on student outcomes, 34% showed a mixed impact (positive and negative or no impacts), 14% showed no impact, and 2% showed a negative impact.

Excellent instruction using methodologies across the inquiry spectrum does not seem to provide greater student learning. In Minner, Levy, and Century (Minner, et al., 2010) there was no statistically significant relationship between student conceptual learning and the amount of inquiry saturation in the study, that is, in comparing active learning scientific experimentation to open inquiry levels (as previously described). Cobern et al. (2010) also found that there was no significant difference in student learning of science concepts and principles when comparing well-designed and executed active learning experimentation and guided inquiry, based on the Biological Sciences Curriculum Study's 5E (Bybee & Fuchs, 2006) teaching models. However, when guided inquiry instructional methods are compared to traditional or textbook instruction there are significant effects on student learning for guided inquiry instruction (Vanosdall, et al., 2007; Wilson, Taylor, Kowalski, & Carlson, 2010).

Guided inquiry, based on the BSCS 5E model (Trowbridge, Bybee, & Powell, 2004) is used in this research study. Table 1 shows a comparison of guided inquiry and common science instruction practices in the US (Hudson, McMahon, & Overstreet, 2002; Weiss, Pasley, Smith, Banilower, & Heck, 2003). The differences are related to when and why the students gather data and when content and terminology is presented. Guided inquiry is student-centered but teacher-led allowing the students' to "discover" a teacher-determined science concept, sometimes known as "ABC - activity before content". Common science instructional practice is to provide the science content and then use various methods to confirm and reinforce that information.

Table 1
Comparison of Guided Inquiry Instruction to Common Science Instructional Practice

Guided Inquiry	Common Practice
Students gather data	Teacher introduces content through a formal presentation
Collect class-wide data results	Teacher verifies content through demonstration
Using the data, teacher guides a student discussion to articulate a scientific concept that is evidenced within the data	Students participate in small group discussion of content
Teacher introduces scientific terminology and definitions	Students practice content through a laboratory exercise
There is further application and elaboration of the concept, often through another cycle of data gathering and analysis	Students answer textbook or worksheet questions about the content
Evaluation	Evaluation

Professional Development Theory of Change

Professional development of teachers has lacked a comprehensive theory and is characterized by research that often relies on case studies, professional judgment, or self-report (Ball & Cohen, 1999; Desimone, 2009). There is also a lack of replication across studies operating within different contexts (Wayne, Yoon, Shu, Cronen, & Garet, 2008) and little rigorous empirical documentation of the links between teacher professional development, classroom practice, and student achievement (Ball & Cohen, 1999; Lawless &

Pellegrino, 2007; Opfer & Pedder, 2011; Scher & O'Reilly, 2009). Our research is guided by our theory of change (Figure 1) positing that strong teacher knowledge and skills and the transfer of those knowledge and skills to the classroom context are critical to promoting student learning.

Research has documented the prevalence of professional development workshops where teachers are typically in a passive role, are often presented with content that is disconnected from the realities of the classroom, and are provided limited follow-up (Garet, Porter, Andrew, & Desimone, 2001; Haymore-Sandholtz, 2002). Professional development is often a "sit and get" approach, without focusing on the background knowledge and characteristics of the teacher, the instructional context, and transfer to classroom practice (Sparks, 2002). Yet, despite the myriad of problems associated with traditional professional development, such training is a reality in American schools and becoming of increased importance in the face of heightened standards for academic excellence for all students. To be effective and sustained in this era of high demand for rigorous standards and educational accountability for *all* students – regardless of educational context and individual differences – professional development efforts must attend to both *content* and *processes* that promote knowledge acquisition and skill transfer. Necessary features include a focus on deepening teachers' content *and* pedagogy knowledge and active teacher engagement in learning opportunities, as well as experiences that are delivered in a highly accessible way to encourage collective participation and collaboration among teachers. The professional development should also be of sufficient duration, and promote continuity to other in- and out-of-school experiences (Garet, et al., 2001; Loucks-Horsely, Love, Stiles, Mundry, & Hewson, 2003). Graduated experiences including instruction, modeling, practice, feedback, and opportunities to adapt newly acquired skills into natural classroom contexts (e.g., through mentoring) are also necessary to achieve desired experiential and learning outcomes. A shift from static, knowledge-based training to supported experiences that provide continuous, practice-focused support and guidance to teachers (Ingersoll & Kralik, 2004; Pianta, 2005) is becoming prominent. Such strategies reinforce teachers' development of evidence-based instructional strategies and application of these desired skills in relevant instructional contexts (Akerson & Hanuscin, 2007; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Our theory of change also recognizes that teacher learning and practice must be conceptualized as a complex system, situated within contextual variables that reflect teachers' background and teaching/learning environment (Opfer & Pedder, 2011). This contextualized approach recognizes that specific professional development programs, processes, and characteristics cannot be examined in isolation from the complex interplay of teacher and environmental variables that influence teacher performance. This situational, contextual, and ecological framing is necessary to provide a more robust and dynamic understanding of the role of professional development in impacting student learning.

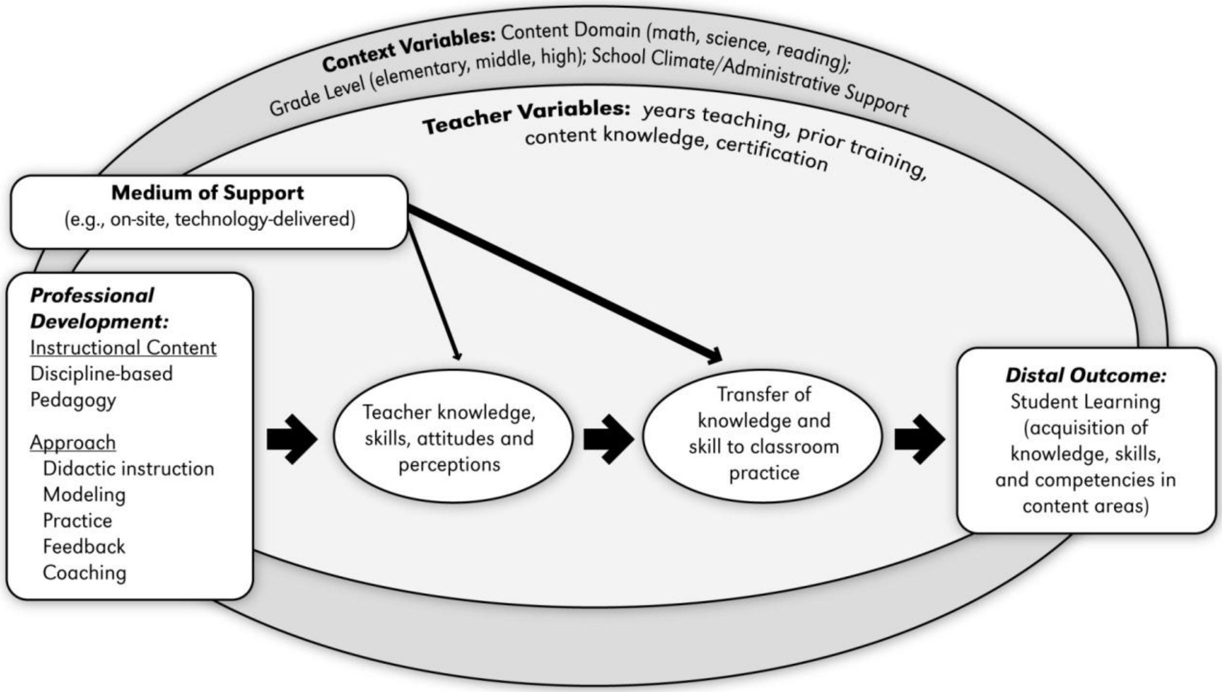

Figure 1
Model of Change from Teacher Professional Development

Coaching

There are many types of coaching discussed in the literature, including peer coaching, cognitive coaching, literacy coaching, content coaching, instructional coaching, differentiated coaching, leadership coaching, etc. (Knight, 2009b). A recent review of the literature on the effects of coaching indicates that there are positive impacts of coaching on teacher attitudes, teaching practice, and teacher efficacy (Cornett & Knight, 2009). Cornett and Knight caution that much of the research on coaching is still relatively new and has been mostly exploratory. However, cognitive coaching increases teachers' job satisfaction over time and has been shown to increase teacher efficacy. Various types of coaching increase implementation rates of professional development within the teachers' classroom compared to workshops that do not have any follow-up. Teacher quality is an important variable in student achievement (Sanders & Rivers, 1996; Wenglinsky, 2000) and the research on coaching suggests that coaching can improve teacher quality and therefore student achievement, but studies are needed to make that link clear.

Literature on science coaching is sparse, limited to one research study, one dissertation, and a few articles on the practical implementation of science coaches in schools. Tobin and Espinit (1989) found that neither of two coaching models (coaching by university science educators or by another high school science teacher) improved a science teacher's instruction. This teacher was asked by the school administration to participate in coaching, and the teacher's beliefs about teaching and learning and poor content knowledge were the strongest barriers to implementing change in his teaching. Implementing science inquiry was the main focus of the other articles. In descriptive studies of science coaching in elementary and middles schools implementing inquiry instruction, it appears that the science coaching helps the teachers implement inquiry instruction in their classrooms and may have an impact on student achievement in science (Bransfield, Holt, & Nastasi, 2007; Dempsy, 2007). Kraus's (2008) dissertation explores how science coaches help high school science teachers overcome the barriers to implementation of inquiry based instruction in an underperforming school district with high poverty. He concluded:

> Coaching does indeed seem to be an effective method for removing the traditional barriers to inquiry and encouraging teachers to adopt inquiry-based teaching methods...The [study] coaching staff has been very successful in overcoming the usual inquiry difficulties stemming from a lack of inquiry knowledge, a lack of content knowledge, or inability to access materials. (Kraus, 2008, p. 169)

The coaching model used in this study was an adaptation of instructional coaching (Knight, 2007, 2009a). Since instructional coaches' focus on helping teachers incorporate research-based instructional methodologies into their classrooms, it seemed appropriate for this professional development experience. In instructional coaching there is a partnership between the teacher and the coach based on seven partnership principles: equality, choice, voice, dialogue, reflection, praxis, and reciprocity (Knight, 2007, 2009a). These principles foster a trust-based relationship that respects the professionalism of the teacher and gives the teacher a strong voice in the process. This becomes a truly collaborative experience for the teacher and the coach, one in which the coach can expect to learn as much as the teachers. Instructional coaches usually work in four areas with teachers: classroom management, content, instruction, and assessment (Knight, 2007, 2009a). In this professional development experience, the coaches spent most of their time working with the teachers on content and instruction.

Coaching Professional Development Experience

This professional development was a result of collaboration between a civil engineering department and an educational research center at a Midwest university. The goal of the program was for teachers to develop and implement a guided inquiry lesson that used the engineering context to teach a science or math concept. There was a two part professional development experience; that included: (1) three days of instructional coaching professional development (Knight, 2007) for teachers serving as coaches (hereafter referred to as coaches); (2) seven days of professional development (split into two sessions) for teachers that included coaching support. The teachers developed the lesson during the second professional development experience with the help of their coaches.

The instructional coaching professional development used materials (i.e., books, DVD, exercises, etc.) from Jim Knight's instructional coaching multimedia kit (available from Amazon.com) facilitated by an education faculty member. Jim Knight was on campus, gave a presentation, and met with the coaches. There was an additional half day of professional development in guided inquiry, led by a science education expert in guided inquiry, which focused on what guided inquiry was and how to implement it within the classroom. Although all the coaches were familiar with science inquiry instruction in the classroom, it was important to have a consistent message about guided inquiry instruction within the classroom for the teachers.

The first session of teacher professional development included three days of guided inquiry and engineering content and time for the teachers and their coaches to begin developing the teachers' lesson. Guided inquiry instruction was related to the 5 E's (Engage, Explore, Explain, Elaborate, Evaluate) (Trowbridge, et al., 2004). The teacher identified a concept for the students to learn and had the students collect data (through an activity or observation) and then, subsequently, the data was combined as a class and the teacher facilitated a discussion that led to students to understand the concept from the data they collected. Then an application or extension of that concept was explored further, usually through another round of data collection and analysis. Engineering content covered topics within highway design, transportation safety, global positioning systems, global imaging systems, engineering as a profession, and environmental, structural, and materials engineering. This information was presented by engineering faculty and graduate students. Tours of engineering research sites on the campus were also included. Engineering resources for teachers to use in their classrooms were provided.

During these three days, time was set aside for the coaches to meet with their teachers individually and in small groups. The goals for these sessions were for the coach to learn about the teacher, explore their topics of interest, learn about their students, and provide help in refining concepts and developing lessons. By the end of the third day, most teachers had outlined a concept and begun to develop the specifics of the lesson. Between the first and second sessions of the teacher professional development, the teachers, with the help of their coaches, refined their lesson plan ideas.

During the second session, the first day was devoted to finalizing lesson plans and identifying what the coach should observe during instruction. This day was largely a working day for coach and teacher. The second day provided opportunities for teachers to present their lessons to their coach and fellow teachers, receive feedback, and refine their lessons once more.

In the final two days, during a science and engineering student summer experience, the teachers presented their lessons to groups of about 20 middle or high school students.

Methods

Research Design

The research design for this study was a descriptive case study (Yin, 2009) of a unique STEM professional development program that included coaching. The case study was conducted during a summer professional development program continued into the teacher's classroom during the school year. Mixed methods of data collection (Creswell, 2002) were employed by the researchers who acted as participant-observers (Yin, 2009). The researchers, in conjunction with a university civil engineering department, planned, developed, and implemented the professional development. Qualitative data included video and audio recordings during the teacher lesson implementation both during the summer professional development and in the teachers' regular classrooms during the following school year, as well as interviews with all participants after the professional development program. Participants were asked what they found helpful in professional development, what they would change, and about specific parts of the professional development, including the coaching, inquiry, and observations. Additional artifacts from the professional development – such as the professional development program manual, lesson plans produced by the teachers, and observation instruments co-developed by the teachers and coaches – were collected. All interview conversations were transcribed. Teacher time spent in different teaching modes was measured using an observation instrument (researcher developed) during the summer professional development, during the implementation of the lesson developed during the summer professional development (inquiry lesson) in their classroom, and during another lesson (normal lesson) in the 2011-2012 school year. This observation measure recorded, for every 15 second interval of class time, what instructional activity the teacher was performing; organization, activities, discussion, lecture, worksheets, or no instruction. For organization, activities, discussion, and worksheets, the instructional activity was also recorded as inquiry or non-inquiry. Lecture was classified as related or unrelated to the science concept being taught.

Quantitative data included knowledge of inquiry (Nugent, Welch, & Bovaird, 2011), science inquiry teaching self-efficacy (Smolleck, Zembal-Saul, & Yoder, 2006), beliefs about teaching science inquiry (Duran, Ballone-Duran, Haney, & Beltyukova, 2009), and engineering attitudes (Douglas, Iversen, & Chitra, 2004), and content (researcher developed covering transportation engineering content and engineering as a profession). Measures, except engineering content and attitudes, were given to both teachers and coaches pre- and immediately post-professional development and after the teachers implemented their lessons in their classrooms (varied from early fall to mid-spring implementation). Teachers completed the engineering content and attitudes measures pre-professional development and immediately after the first week of professional development. Coaches did not complete the engineering measures because all but one had been prior participants of this professional development experience (some multiple times) and been exposed to the engineering content before.

The inquiry knowledge measure (Nugent, et al., 2011) consists of three sub-scales. The science inquiry scale measures knowledge of inquiry in science and the nature of science. The classroom inquiry scale measures knowledge of the steps of the scientific process, including data collection and analysis as applied in a classroom setting. The inquiry pedagogical content knowledge (PCK) scale measures a teacher's propensity towards types of instruction. Each question presents a teaching scenario and asks the teacher to choose what they think is the best approach for teaching in that situation. There are four choices: one which describes a direct didactic model, such as lecture with a demonstration; one which describes a direct active model, such as lecture followed by a confirmatory laboratory experience, and two inquiry options. The first inquiry choice describes guided inquiry, where there is data collection directed toward developing a scientific concept for the students, and the second choice describes open inquiry, where the materials are provided but little or no instruction is given on what to do with them and the focus is on exploring the phenomenon.

The science teaching self-efficacy measure (Smolleck, et al., 2006) contains 34 teaching self-efficacy items based on the national science standards (National Research Council, 1996, 2000) for teaching science inquiry. It is designed to measure teaching self-efficacy of science teachers for science inquiry. The beliefs about inquiry teaching measure (Duran, et al., 2009) contains 30 items about teaching science inquiry. Prior research (unpublished) with those items suggested that there were factors related to beliefs about improvements to student engagement (8 items) and student learning (5 items), and barriers to implementation (4 items) of science inquiry within a classroom. Engineering attitudes (Douglas, et al., 2004) had 11 items relating to attitudes towards engineering as a profession, relationship between engineering and math and science, and using engineering in the classroom.

Data Analysis

The data analysis was focused on (a) teacher and coach conceptualizations of the professional development implementation and (b) teacher, coach, and student outcomes from the professional development. The qualitative data were coded for ideas that indicated the important elements and outcomes of the professional development. Four researchers met after an initial reading of an interview transcript. Codes were developed and then applied to other interview transcripts. Researchers met again and refined the codes. This iterative process was repeated until codes were well defined. Then the researchers coded each transcript with the agreed upon codes and then checked the coding of transcripts already coded. In this manner, every transcript was coded twice and any disagreements in coding were discussed among the researchers. Lesson plans developed during the professional development were coded using a researcher developed rubric based on the guided inquiry instructional method used in the professional development (appendix). The quantitative data was analyzed using SPSS vs. 19. Because of the small sample size, Wilcoxen Signed Rank tests were used.

Three types of triangulation were used to ensure credibility. (1) Inter-research reflection occurred through having multiple researchers code the data and meet repeatedly to discuss and refine the coding (Yin, 2009). (2) Triangulation with theory occurred through discussion of relevant literature (Yin, 2009). (3) Mixed methods data triangulation of multiple sources of data was used to understand the research questions (Creswell, 2002; Yin, 2009).

Results

Participants

There were seven coaches, all of whom were science or math teachers in large, urban or suburban middle or high schools in the Midwest. Six of the seven coaches were current science teachers and one coach was a current math teacher who also had science teaching experience. The coaches were selected from either a pool of prior participants in professional development experiences hosted by the engineering department and education research center or were nominated by science curriculum coordinators from local school districts. Coaches were selected for knowledge of inquiry practices and leadership experience in schools. Teaching experience among the coaches ranged from four years to more than 30 years (average was 18 years). There were five male and two female coaches. Six of the seven had Master's degrees, two in math or science content. One was pursuing a doctorate and another had been enrolled in a science doctorate before switching to teaching. All had various leadership experiences in their schools such as: team leader, assessment and advising leadership positions, department chair, mathematics coach, and in staff professional development. One was involved in staff development at the state and national level and another led the implementation of an inquiry physics curriculum in his high school. Many had science and science education experiences outside of the school; three were involved in informal science experiences for students and two had extensive science research experiences. Finally, one was a recipient of the Nebraska State Science Teacher of the Year.

There were thirteen teachers that began the professional development. The two elementary teachers dropped out of the sample after the first week. Their results are included in the engineering content and attitudes only. Because they were being coached by the same coach, who then had no teachers to coach, another teacher was re-assigned from a different coach using content area and geographical proximity for fit criteria. One other teacher dropped out after the summer professional development and did not complete an interview, follow-up measures, or teaching observation. There were nine science and mathematics teachers who taught in suburban and urban middle and high schools in the Midwest that completed most (exceptions noted in the results) of the requirements of the professional development. There were five male and four female teachers with four teaching math and five teaching science. Teaching experience ranged from a new graduate from a local university to 13 years (average was 5 years). Most had been teachers from the beginning of their careers, except one math teacher who had 20 years' experience in business before switching to teaching.

Table 2

Questions to Develop Concept from Data

Geometry – Bridges and Triangle Congruence (Rubric Score 1)
How many parts do we need?
Does the order matter?
Why is HL only two if we need three parts?
Calculus – Estimating Finite Sums (Rubric Score 2)
How have you determined the shape of the rectangle?
What do you notice about the speeds for this train compared to the first train?
What does it mean to approximate?
Is this different than finding the actual distance traveled?
How do you think we should approach approximating?
What shape can be used that you can easily find the area of?
How did your estimate compare with the actual?
How else could you place the rectangles to approximate?
What do you think that would do to the approximation?
Do you think positioning this way always results this way?
What do you impacts the estimation?
Can you think of another way to position the rectangles?
How do you think this compares to the other two methods?

Inquiry Lessons

The lesson plans were coded as in the appendix. The teachers' scores ranged from a five to seven out of a possible eight (M = 6). All of the teachers designed a lesson with the activity before the concept development and ended with an application. Most of the teachers were able to design an activity for data collection that clearly led to the concept. However more than half of the teachers did not generate questions that would clearly lead to the concept; for an example see Table 2 which compares two math teachers' questions developed in their lesson plans. The first teacher has three questions listed to examine six triangle congruencies, whereas the second teacher has given thought to many different ways to help the students see patterns in the data for estimating the area under a curve without using calculus. Additionally, none of the teachers were able to clearly define the concept they wanted to teach; all of them had a partially defined concept. Usually, the teachers were not able to distinguish between the scientific or mathematical terminology and the concept behind it. For example, a middle school science teacher's concept was "Introduce and understand Newton's 3 laws.", and from a high school science teacher "Introduce RFID & application to real life scenarios."

Seven of the nine teachers had classroom observations coded (Table 3). One teacher's school did not permit video recording in the classroom and another teacher's classroom was missed. Each teacher was videotaped for the lesson they developed during the professional development (inquiry) and one other lesson (normal). Inquiry instruction was coded during the organization, activity, discussion, and worksheet times but not for

Table 3
Observation of Teacher's Inquiry and Normal Lessons

Teacher/Lesson[1]	Inquiry	Non-inquiry	Org.[2]	Activity	Discussion	Lecture	WS[3]
Science Teacher 1							
Inquiry	72%	24%	19%	36%	45%	0%	0%
Normal	0%	67%	7%	37%	4%	15%	36%
Science Teacher 3							
Inquiry	64%	4%	22%	31%	9%	26%	11%
Normal	0%	90%	18%	54%	0%	6%	23%
Science Teacher 4							
Inquiry	86%	5%	20%	44%	2%	8%	26%
Normal	0%	56%	23%	22%	0%	44%	11%
Science Teacher 5							
Inquiry	7%	75%	16%	42%	18%	17%	7%
Normal	0%	78%	19%	54%	7%	21%	0%
Math Teacher 1							
Inquiry	33%	59%	7%	29%	38%	4%	21%
Normal	0%	97%	19%	0%	16%	0%	64%
Math Teacher 2							
Inquiry	51%	40%	30%	48%	21%	1%	0%
Normal	0%	48%	20%	0%	0%	52%	28%
Math Teacher 3							
Inquiry	97%	3%	7%	80%	13%	0%	0%
Normal	0%	44%	8%	0%	28%	56%	7%

[1]Inquiry and non-inquiry do not add up to 100% because lecture was not counted nor was non-instructional time.
[2]Org. is organization, preparing the class for an activity or other directions
[3]WS is worksheet, students working on prepared worksheets.

lecture. However, it was noted that for most of the inquiry instruction, the lecture was done after classroom discussion and as a follow-up to concept development. Six of the seven teachers spent more time during their inquiry lesson using guided inquiry instruction. Science Teacher 5's two lessons look substantially the same across all the categories. He is the teacher who began the professional development right after graduating from college (first year teacher). Most teachers have more discussion in the inquiry lesson and less lecture. Amount of time actually spent on the activity varies between lessons with no clear pattern among the science teachers, although there are no activities in the normal math lessons.

Elements of the STEM Professional Development

Teacher interviews were coded for important elements of the professional development and specific questions were asked about inquiry and coaching. There were five main themes that emerged as the important elements (aside from inquiry and coaching): time, specific inquiry instructor, engineering content, and teacher interactions. Four of the coaches and four of the teachers mentioned time as important in the professional development. They appreciated the time that was built into the professional development experience to develop and refine their lessons. During the 56 hours of professional development they were given about 5 hours the first week and 6 hours the second week to work on their lesson with their coaches available to help. Six coaches and four teachers mentioned a specific instructor for inquiry. There were two people who worked with the teachers on inquiry. These people uniformly found one specific instructor outstanding at demonstrating how to teach through guided inquiry. His presentations all used guided inquiry as a method for teaching about guided inquiry which was an important element of the inquiry instruction.

> [The instructor] did a great job, where you don't have to agree with his definition exactly but you have to have a working definition of what inquiry is and *have it modeled in front of you*…[in a prior professional development] I remember being very confused of what inquiry was, how far on the spectrum you have to be. (Science Coach 2)

> I thought the most helpful thing for me was the inquiry portion with [the instructor]…I was afraid before because we'd talked about it before but *I'd never seen it.* (Science Teacher 5)

All but one of the teachers and coaches mentioned the engineering content. However, there was a lot of disagreement about the appropriateness of the content. Many teachers found it very interesting and revealed that they learned a lot about engineering, while others found the content too difficult and/or not relevant to teaching their students. Five of the participants actually had both comments, that some of the content was good, or the tours of the engineering facilities were important but other content was not good. The engineering content was provided by faculty and graduate students from engineering and was uniformly presented in a didactic power-point presentation style. Most of the engineers have had little or no contact with middle and high school students.

Five of the coaches and eight of the teachers indicated that they thought the opportunity to interact with other teachers was an important part of the professional development. They saw this as an opportunity, that often doesn't come up during the school year, to get ideas from other teachers, to work with teachers from different school districts and in different subjects, to brainstorm ideas, get feedback, and relieve the isolation of teaching, which occurs during the school year. One coach summed up this idea well;

> I'm just thankful for the opportunity because it's hard to find opportunities where you get to work with other teachers. Being a teacher, you rarely have opportunities to work with your peers and bounce ideas off each other, it's just not built into the teacher framework, so this is great for me, not only to help the teachers I was paired up with, but I was also taking to other teachers and other coaches and anytime you get teachers together like that, we're gonna talk about work and school and we're gonna bounce ideas off each other and we're gonna get better because of it. (Science Coach 2)

When asked about inquiry as an instructional method, eight of the nine teachers and four of the seven coaches evidenced changes as a result of the professional development. Three science coaches and all the science teachers indicated changes in at least one of the following: knowledge, attitudes and beliefs, or classroom practice. The math coach and three of the math teachers indicated the importance of learning a new instructional methodology.

Science participants indicated that they learned more about inquiry and understood teaching through the inquiry instructional methodology better after the professional development. Some were confused before the professional development and this cleared up their understanding (see the earlier quote from Science Coach 2 about being "confused" about inquiry). Another teacher indicated just how confusing teachers find inquiry in the following quote:

> He [the instructor] kind of helped me understand what inquiry is supposed to look like. That helps me because next week I'm leading with the help of my [district personnel], I'm leading this inquiry thing for [his school district]. How it is supposed to look. Before [this professional development experience] we had three day meetings about what inquiry is supposed to look like and people argued about it. We kind of settled on something, then when I was at [this professional development experience], I was like – Wow! This is easy. (Science Teacher 1)

The teachers and coaches felt that this professional development cleared up their understanding of inquiry and many realized that inquiry could be something more than open, unguided, student activities. The guided inquiry model taught in this professional development struck a cord in these teachers, instigated a change in their beliefs about inquiry and their ability to implement it in their classrooms.

> I had a very loose, probably incorrect understanding…now I feel like I'm on the right track with what inquiry is…I really do feel like after hearing what he [the instructor] had to say about it that it is something that I can do, anyone would be comfortable with. I'm not a control freak, but I like knowing what's going on in my room and I don't like just saying 'go,' before this, if I were a kid I'd be like 'what am I exploring?' You know? I can look at this all day, but if I have no direction from somebody else then I just sit there. So, in that way, I feel like the idea of inquiry was really, it really

> shaped my idea of inquiry, so that's what I now view inquiry as. (Science Teacher 5)

This teacher has changed his understanding of inquiry, his belief in his ability to teach this way, and that it is something he can do in his classroom. Even the coaches, who had experience with inquiry, indicated changes in the way they would practice inquiry in their classroom.

> He [the instructor] set it up as an inquiry activity and taught us inquiry through inquiry which totally I got excited…I could do this more..I can put it in my classroom like daily, like small activities, warm ups, parts of labs that don't take three or four days to put together…to get inquiry mixed into one of those things I do every week, where there is a 5 or 7 minute inquiry activity where it kind of takes pressure off of taking notes and me talking and lecturing. That was good, I think probably a lot of teachers felt the same way that it doesn't have to be four days of planning formal activities. (Science Coach 4)

The math teachers and coach saw the inquiry instructional methodology as a way to incorporate active learning into their classrooms. They were being asked to use more active learning in their teaching but many felt they did not know how to do so. This instructional methodology added a tool to their instructional tool belt, which they were glad to have. Math Teacher 1 said "I learned a lot more, especially the different types of teaching, to bring that into it was huge."

> [The school district] is really pushing what is called 'cooperative learning' and cooperative learning is just another term for inquiry method, which you do activities where you are discovering what the answer might be or discovering how to find what the formula could be or discovering different ways of solving this problem and you do it in groups, teams, pairs…I think it worked as well for all the math teachers and, you know, to create an inquiry/cooperative learning lesson (Math Coach 1)

Inquiry Coaching

The coaches defined their roles during the two week professional development in many different ways. They felt it was important to establish a relationship with their teachers that was trusting and based in professional respect, and it was important for the teacher to understand the coach was for their benefit, not as an evaluator or supervisor.

> You have to build a relationship, try to just talk and get comfortable and show that you care about the teacher you're gonna help coach, and then another big thing was trying not to show that I'm the expert and I'm gonna teach you how to do something, I think that was important, we store that in our minds, that we're just other teachers, just like you are, and we're just trying to help you make your lesson better. (Science Coach 2)

The coach needed to be a mentor and supportive for their teachers. Math Coach 1 said "when you're a coach, you have to kind of go along with how a teacher already does things and gently guide them into new experiences without being overbearing and pushy". Coaching involved providing a sounding board for new ideas, refining existing ideas, providing encouragement, helping to find supplies, and providing feedback to the teachers.

> You just try to make connections, which, you know, building relationships is what you'd actually do or you're in the wrong job, just to continue to be supportive about that and just to make sure, do you have the supplies, what else do you need, what's gonna be best for your lesson, have you thought about this, have you thought about this? (Science Coach 1)

Another important aspect of coach, which was commented on by almost all of the coaches and teachers, was the coach and teacher match. Unlike in Jim Knight's instructional coaching model (Knight, 2007), we found that matching content area was considered important by most of the participants. Because there were more math teachers than coaches, three of the math teachers were paired with science coaches. Two of these three felt that this limited the help the coach could provide them.

> Nothing against [Science Coach 5], but him being a science teacher and being a coach for a math teacher, I mean, he did have some good suggestions but they were coming from a different background so for him to suggest things, this might work, this might not work, it's hard, because it's been how long since he's had geometry. He'd say "you should try this" when that really had nothing to do with what I'm doing. But he was a good listener and he did offer some good suggestions and his observations were helpful. (Math Teacher 3)

The other math teacher (Math Teacher 4) mentioned the content mismatch but did not feel it was a problem; in fact she indicated "probably you do get better feedback from people who aren't intimately involved in it because they're trying to understand it". The strongest mismatch came when we inadvertently matched a science teacher and the department head from his school. We did try to match teachers and coaches by proximity (as they came from two urban areas about 60 miles apart), but did not realize the supervisory relationship that the coach had with the teacher. The teacher was unable to separate the two roles and therefore, the coach was unable to build the supportive relationship that was important for a good coaching relationship. The teacher felt that the coach was judging him and did not have a positive experience with the coaching, although there were other things he liked about the professional development experience.

> His role was to write down observations about me, in the end that's what I kind of saw him doing. We really didn't work together that closely…I don't know what to say. [Science Coach 5] never taught 9th grade, he doesn't teach 9th grade at all…There were a lot of coaches and it wasn't fair to [Science Coach 5] because he's my department chair…and so with somebody else, because I know him, if the coach had been from another school I didn't know, it probably would have been a different experience. (Science Teacher 4)

Other participants commented on the positive aspects of their match, even if they were not teaching exactly the same science subjects or grade levels, they would have something in common in school types or students which was helpful.

> They have 9th graders primarily too. They are not too far to move from middle school. And I have some junior, senior in my class too, that works pretty good. We still teach the same teaching principles that apply, subject matters change a little bit. (Science Teacher 2; HS Geoscience teacher, Coach teaches MS science)

One thing that was really good was that [Science Coach 4] has experience in the school like [the teacher's school] so we had really good conversations about teaching at a school like that was really nice. (Science Teacher 5; MS Science Teacher; Coach teaches HS physical sciences)

Other than Science Teacher 4 (department head as coach), the teachers indicated that the coaching process was mainly a positive experience. In general, the more mismatched the teacher and coach the less the teacher felt the coach was helpful. The teachers felt the coaches improved their understanding of inquiry, how to teach through inquiry, and positively impacted the quality of their lesson. They indicated the coaches provided feedback, helped them in lesson development, and observed their lesson.

He [the coach] just knew what problems would come up because he was there before. He was really good at setting it…laying it all out and just knowing what I have to fill in this spot and that spot, thinking about [the instructors'] three or four categories with inquiry. He really, you know, I kind of threw up and idea and he kind of analyzed it and shot it back to me and that made me change it. Really good at editing. Yeah, he was a good coach, definitely. (Science Teacher 1)

Oh yes, she [the coach] was definitely a good resource for me…she was there for it. She was pushing more ideas towards me. She listened to different presentations and write down different ideas from people. So that helped a lot…She looked at my lesson [observed her teaching her lesson] and she said, "You know, that really didn't work, maybe we should try this next time" or "That worked really well, but this could maybe help even more." You know, so it was just nice to have someone else taking those notes – because you can't see it. So I think it helped…And then bouncing off ideas at the same time was awesome too. (Math Teacher 1)

Engineering and Inquiry Knowledge and Beliefs

There were a few statistically significant changes in the seventeen coaches' and teachers' content and attitude scores. The content measures of science inquiry, classroom inquiry, and engineering only exhibited significant improvement in the engineering content (Table 4). Although there was an improvement in science inquiry knowledge from pre- to

Table 4
Content Measures

Content	Pre-measure	Post-measure	*p*-value[4]	Follow-up[5]	*p*-value[4]
Science Inquiry[1]	59%	65%	.305	68%	.130
Classroom Inquiry[2]	75%	74%	.822	73%	.305
Engineering[3]	58%	73%	.007		

[1]Content related to understanding what is scientific inquiry, including nature of science
[2]Content related to science inquiry processes in the classroom, including steps of scientific process
[3]Content related to both engineering as a profession and civil engineering content (not given as follow-up), N=10
[4]Compared to pre-measure for *p*-value
[5]N=15 instead of 17

post- and follow-up, this was not significant and there was no change in classroom inquiry. Science inquiry knowledge was presented only as related to understanding how to teach through guided inquiry and classroom inquiry was not explicitly addressed in the professional development.

There were more significant changes in attitudinal scales but none of them stayed significant through the follow-up period (Table 5). There was a significant increase in the inquiry pedagogical content knowledge and engineering attitudes from pre-professional development to post-professional development. There were also changes at less than the 0.1 level (p-value) for teaching self-efficacy. The participants moved from a nearly guided inquiry stance to a more open inquiry stance right after the professional development but then back to a guided inquiry stance in the follow-up. Attitudes towards engineering improved as a result of the professional development experience. There was a short increase in teaching self-efficacy for science inquiry instruction that fell back by the time of the follow-up. Beliefs about the impact of inquiry teaching on student engagement, student learning, and barriers to implementation of inquiry instruction stayed the same.

Table 5
Attitudinal and Belief Scales

Scale	Pre-measure	Post-measure	*p*-value[5]	Follow-up[6]	*p*-value[5]
Inquiry PCK[1]	2.96	3.16	.021	3.07	.428
Engineering Attitudes[2,3]	3.91	4.32	.002		
Teaching Self-Efficacy[2]	3.95	4.13	.088	4.01	.798
Inquiry Beliefs[4]					
Student Engagement	4.10	4.21	.358	4.12	.724
Student Learning	4.03	3.96	.419	3.87	.429
Barriers	3.00	2.95	.753	3.17	.782

[1]Scored on a 4-point scale 1-direct traditional, 2-direct active, 3-guided inquiry, 4-open inquiry instruction
[2]Scored on 5-point scales 1-strong disagree to 5-strongly agree
[3]N=10
[4]Scored on 4-point scale of 1 strong disagree to 4 strong agree
[5]Compared to pre-measure for *p*-value
[6]N=15 instead of 17

Conclusions

Overall the coaches and teachers found this professional development experience to be positive and informative. The teachers and coaches improved their knowledge and application of guided inquiry and engineering. Most teachers developed a guided inquiry lesson that they will be able to use in their classrooms for many years to come. The coaches were a valuable part of this professional development experience and had a positive impact on the lessons developed by the teachers. Important factors in the coaching process were building an equitable, respectful, and trusting environment for the teachers. It was important for the teachers and coaches to be matched in similar content areas and student level, although level of student was less important than content match. It appears to be very important that the coach not have an additional supervisory relationship with the teacher. The coaches provided a sounding board for teacher ideas, provided feedback on lesson development and teaching, offered suggestions for the lessons, and helped the teachers understand guided inquiry.

Limitations of this study are related to the small sample size and unique professional development experience. Given the small sample size, the coaches' and teachers' statistical data were analyzed together, although the coaches were selected for their greater knowledge of science inquiry and guided inquiry instruction. This may have had a ceiling effect for some of the measures with changes in the teachers not seen because of coach influence in the data. However, coaches did report changes in their knowledge, attitudes, and practices. Moreover when looking at the data individually, there were coaches whose scores changed. A small sample size has a reduced power and, therefore, any significant changes are likely to be the result of a large effect. Lack of significant results may simply indicate that there were not enough participants.

While there are few studies of science coaching generally, this study employs science coaches in a more limited fashion, almost entirely within a summer professional development experience, rather than within the school day setting. Additionally, these coaches were employed to help teachers create a new guided inquiry lesson, something that can be difficult for teachers to do. Therefore, results related to science coaching have to be interpreted within that context and may or may not transfer to a school science coaching setting.

Teachers learned more about engineering from this professional development (Tables 4 & 5). The statistical results indicate that they learned more engineering content and that their attitudes towards including engineering within their classrooms improved. All of the teachers and most of the coaches indicated that the engineering content was an important part of this professional development experience but many felt that the content was not as relevant to teaching science and math in middle and high school as they would like. Many of the teachers had difficulty determining how to take the often complex engineering presentations and applying them to their classroom situations. Generally, the coaches were able to help them with that application process, because all but one of them had been involved with science, math, and engineering professional development experiences provided by this engineering department before.

It was evident that developing a clear concept and questions to facilitate the student discovery of that content was difficult for these teachers. None of the teachers were able to clearly articulate their concept in their lesson plans. Although not all the teachers submitted both a lesson plan and had their classroom inquiry lesson observed by the researchers, for those that did have both there was revealing pattern. The teachers who scored 0 or 1 on concept invention (Science Teachers 3, 4, & 5, and Math Teacher 3) had a lower percentage of time spent in classroom discussion (9%, 2%, 18%, and 13% respectively – Table 3) than those with scores of 2 (Science Teacher 1 and Math Teacher 1, 45% and 38% respectively). Those teachers who had developed many possible questions to help facilitate a discussion with their students about the patterns in the data they had collected and thought through how this would lead to the concept they were teaching spent more of their class time in discussion. Being able to clearly define the concept the students will learn is the basis of knowing what the object of the lesson is. Most teachers had no trouble developing activities for the students to do or connecting those activities to a concept a priori (in their minds), but leading the students to discovery of that concept was difficult for them. These are two areas in which science coaches could be very helpful.

Whether the coaches spent time in this was not evident from this data (and the actual recorded teacher and coach conversations have not been analyzed at this time). However, from this data, it seems important that the coaches spend time helping their teacher clearly define a concept and then, after the data collection activity has been determined, also help them develop a complete set of questions to use to facilitate student discovery of that concept from the data. If the students don't actually develop the concept from the data before the teacher begins to introduce the terminology then this instructional method loses much of its effectiveness.

The newly graduated teacher (Science Teacher 5) was very enthusiastic about this experience and how much he had learned through it. However, he had one of the lowest scores on the lesson plan development (5) and was the only teacher whose inquiry and non-inquiry lesson observations appear very similar, (Table 3) neither of which were substantially guided inquiry lessons. He also felt his coach was vitally important and was the only teacher to indicate a plan to continue the relationship outside of the bounds of this professional development experience. So, although he reported many gains in knowledge, beliefs, and practice through this experience, it was not evident in his teaching. This is probably a result of being a first year teacher for whom everything is new and has to be developed and implemented for the first time. It is probable that continued coaching with this teacher would improve the lesson that he developed and taught (Kraus, 2008).

Seven of the eight teachers and three of the coaches reported that this professional development impacted their understanding, beliefs, or practice of science inquiry. However, the quantitative results are not completely consistent with the teachers' self-reports. Many of the participants reported being confused by what science inquiry was prior to this professional development. Given the complexity of science inquiry in the literature, their confusion is understandable. Most teachers did not have a sophisticated understanding of science inquiry and most of the science teachers knew it was a standard they had to teach and a teaching methodology. They mostly thought inquiry was unguided student exploration, which was not something they were comfortable doing in their classrooms. For the math teachers, this was new content. However, most participants reported a greater understanding of guided inquiry through this experience. There was only one statistically significant difference in measures of science inquiry (Tables 4 & 5): in inquiry pedagogical content knowledge (inquiry PCK scale) from pre-professional development to post-professional development but not through the follow-up after implementation of their lesson. This is actually consistent with the teachers' reported changes. They mostly reported changes in their understanding of guided inquiry as an instructional methodology, which was what was being measured in the inquiry PCK scale. Science inquiry and classroom inquiry were not inquiry content topics emphasized in this professional development.

For beliefs and attitudes, there were no significant changes in the sample pre- to post- to follow-up, although the teachers did espouse some belief changes (mostly in their confidence to perform guided inquiry). Beliefs are often held very deeply, are not easily subject to change, and influence teaching practices. The beliefs instrument measured a broad spectrum of beliefs about teaching inquiry that went beyond the comments the teachers made in their interviews. The teachers felt more confident in implementing guided inquiry in their classrooms during the interview (mostly held during the summer following the professional development) and this was also indicated by a slight change that neared significance in science inquiry teaching self-efficacy post-professional development. However, this number was back to its original score by the follow-up.

These statistical results for the beliefs and inquiry PCK indicate that long-term change will take long-term professional development. This professional development could easily be science coaching that occurs during the school year while the teachers are employed in their classrooms, where the coach can interact with the teacher, their students, and their curriculum to hopefully make lasting changes. Certainly, the results from this study suggest science coaches can help teachers successfully develop and implement a guided inquiry lesson. Preliminary results from other studies (Bransfield, et al., 2007; Dempsy, 2007; Kraus, 2008) of science coaches in elementary, middle, and high schools also indicate that this is one way to help teachers overcome the inherent difficulties in teaching science inquiry within their classrooms.

Appendix

Scoring Rubric for Lesson Plans:

1. Is the order consistent with students being able to develop the concept from data? Scored 0 – concept introduced before activity or data collection, 1 – activity or data collection introduced before concept
2. Is the concept clearly defined? Is it a concept or a term(s)? Scored 0-no concept, 1-partially defined concept, 2-clearly defined concept
3. Exploration by students – do the students collect data that can be used to determine the concept? Scored 0-no data collection, 1-data collection, 2- data collection that clearly lead to concept
4. Concept Invention – do students develop the concept being facilitated by the teacher through well thought out questions? Scored – no questions listed, 1-some questions, 2- questions the clearly would lead to concept
5. Apply – do the teachers have an expansion idea or application for the concept even if there is no time to do it in the summer professional development? Scored 0-no application, 1-application

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