Developing PCK for Teaching Teachers through a Mentored Internship in Teacher Professional Development

Deborah L. Hanuscin
Deepika Menon
Eun Ju Lee
Suleyman Cite
University of Missouri

Abstract

Pedagogical Content Knowledge (PCK), according to Shulman (1987), is what makes possible the transformation of disciplinary content into forms that are accessible and attainable by students. This includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction (Magnusson, Krajcik, & Borko, 1999). Recently, researchers have argued that a parallel form of PCK exists for science teacher educators (Abell et al., 2009). Nonetheless, little is known about the process through which teacher educators develop their PCK, and more specifically, how doctoral programs can support prospective teacher educators in this regard. The aim of this study was to understand how a mentored internship experience within a teacher professional development program contributes to the development of doctoral students' PCK for teaching teachers. Through self-study, three graduate students and their faculty mentor documented the development of their PCK throughout the mentorship.

Introduction

Pedagogical Content Knowledge (PCK) has gained increasing recognition as a useful framework for characterizing the specialized knowledge of science teachers. Recently, researchers have argued that a parallel form of PCK exists for science teacher educators (Abell et al., 2009). Nonetheless, little is known about the process through which teacher educators develop their PCK, and more specifically, how doctoral programs can support prospective teacher educators in this regard. The aim of this study was to understand how a mentored internship experience within a teacher professional development program contributes to the development of doctoral students' PCK for teaching teachers.

Theoretical Framework

Pedagogical Content Knowledge

Shulman (1987) first introduced the notion of PCK as a fundamental component of the knowledge base for teaching. PCK, according to Shulman, is what makes possible the transformation of disciplinary content into forms that are accessible and attainable by students. This includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction. It represents the synthesis of teachers' knowledge of both subject matter and pedagogy, distinguishing the teacher from the content specialist. The development of PCK involves a dramatic shift in teachers' understanding

> from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students. (Shulman, 1987, p. 13)

Shulman's model has been elaborated upon and extended by other scholars (e.g.,Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). While PCK is typically conceptualized as topic-specific, teachers also need discipline-specific knowledge (Davis, Nelson, & Beyer, 2008). Veal and Makinster (1999) similarly described taxonomies of PCK which include general and domain-specific PCK. Along these lines, Abell and colleagues (2009) proposed that there exists a specialized knowledge for *teaching teachers* that teacher educators develop, or PCK for teaching teachers.

Pedagogical Content Knowledge for Teaching Teachers

This notion of PCK for teaching teachers is supported by the work of Smith (2000), who used Shulman's (1986) PCK construct as a framework for designing and reflecting on her science methods course. Extending on Shulman's work, Smith outlined four important ideas for teacher educators to facilitate future teachers' growth as elementary teachers: knowing about (1) the conceptions that students bring to the methods class, (2) strategies for teaching them, (3) curriculum materials and activities that are effective in helping them construct knowledge of elementary student's naïve ideas, and (4) representations of content that help preservice teachers learn. To develop her own PCK for teaching teachers, Smith drew on several sources of knowledge. These included knowledge that had proved useful and important in her own teaching of children, observations of experienced elementary teachers who teach in ways compatible with the reforms, and research on science teachers' knowledge and its relation to student learning in science. More recent work by Appleton (2008) posited the sources of PCK for teaching teachers may be drawn from one's own experience in a teacher education program, professional development experiences, and graduate coursework. Furthermore, he emphasized that mentoring can play a significant role in supporting the development of PCK.

Mentoring and PCK

Kochan (2002) conceptualized successful mentoring as having three dimensions; relational, reflective, and reciprocal. The *relational* dimension addresses the commitment of mentor and mentee, a sense of caring, and collegiality in working together and effectively communicating. The *reflective* dimension addresses mutual understanding of the purposes of mentoring, willingness to scrutinize and reflect on partnership functioning to evolve with professional growth, and reflection on the extent to which the purposes of mentoring are being met. *Reciprocity* in mentoring is drawn from common values, mutual respect, and joint benefits for mentor and mentee. Using Kochan's framework, Appleton (2008) emphasized that mentors can support mentees' PCK development and contribute to lasting changes in teaching practices.

Based on this literature, we believe that mentored experiences for graduate students can provide a viable means through which they can develop their PCK. In this study, we used self study to explore how three graduate students developed their PCK for teaching teachers within a professional development program for K6 teachers.

Context of the Study

This self-study focused on the collaboration of a science educator (mentor) and three graduate students in science education (mentees), and took place in the context of a state-funded teacher professional development program for which the science educator serves as director. Quality Elementary Science Teaching or "QUEST" consists of a 2-week summer institute and academic-year follow up activities for K-6 teachers. The content of the program focuses on physical science content (light) as well as the 5E learning cycle (Bybee, 1997) and "seamless assessment" (Abell & Volkmann, 2006). Participating teachers take the role of learners in week 1 of the summer institute, developing their subject matter and pedagogical knowledge. In week 2, they shift back to the role of teacher as they design and implement a week-long ½ day science program for students. The graduate students interning with the program participated in the design and implementation of the light curriculum used in the program.

Over the course of a semester, the group collaborated on developing a week-long instructional unit on light for teachers. The curriculum was designed specifically to model the pedagogy of the learning cycle and the use of formative assessment seamlessly throughout, so that teachers would be prepared to utilize this approach in the second week of the summer institute. Our process included meeting weekly to review relevant science education standards, identify big ideas to focus on in the unit, gather potential lesson activities and assessments, and review the literature.

Method

The research relied on self-study (Loughran, 2005, 2007), a method that draws from and builds upon the traditions of reflective practice, action research, and practitioner research. According to LaBoskey (2004), self-study is (1) improvement-aimed; that is, it involves evaluating practice and reframing thinking; (2) interactive; in that it involves engaging with colleagues, students, the literature, and one's previous work to confirm and challenge one's thinking; (3) reliant on multiple, primarily qualitative data sources; and (4) revolves around a need to formalize one's work and make it available to the professional community. As a form of case study, the results of self-study are not intended to be generalized across populations. Nonetheless, this form of inquiry provides in-depth descriptions that illuminate the complexities of teaching and articulate the "wisdom of practice" (Shulman, 2004); consistent with PCK as a theoretical framework. Self-study not only helps those engaged in this type of scholarly activity address problems in their own immediate teaching contexts, but can produce knowledge that "teacher educators in other settings can draw on and adapt to their own teacher education settings" (Dinkelman, 2003, p. 11).

In the context of this program, self-study became a process for improving our own PCK, as well as generating new knowledge to be shared with other science teacher educators. The research questions that guided our self study included:

1. In what ways did the mentored internship contribute the development of our topic-specific PCK for teaching teachers about light?
2. In what ways did the mentored internship contribute to our discipline-specific PCK for teaching teachers?

Data Sources & Analysis

We relied on multiple data sources to answer these questions. To access and represent our PCK, we constructed a "Resource Folio" using the Content Representation Tool (CoRe) and Pedagogical and Professional Experience Repertoire (PaPer) developed by Loughran and colleagues (2006). A CoRe consists of a matrix that outlines important aspects of teaching and learning of specific science content. It addresses what teachers intend students to learn and why it is important, difficulties/limitations connected with teaching the content, knowledge of student thinking and particular ways to ascertain student understanding, and specific teaching procedures and reasons for using them. We modified several of the categories of the CoRe slightly, in order to accommodate our use of this tool prior to planning the instructional unit, and in particular the 5E learning cycle. For example, we specified "*Which activities would be useful for each phase of the learning cycle*?" versus simply, "*Teaching procedures (and particular reasons for using those).*" Similarly, we asked, "In what ways could you (formatively and summatively) assess teachers' understanding or confusion about this concept?" versus simply "ways of ascertaining students' understanding." Because, as novice teacher educators, we were still developing our PCK, we also relied on the literature as a source of knowledge about students' thinking, such as common misconceptions. The CoRe was collaboratively constructed throughout the semester prior to the summer institute, and adapted throughout.

A PaP-eR is a "narrative account of a teachers' PCK that highlights a particular piece, or aspect, of science content to be taught" and "is designed purposefully to unpack a teachers' thinking about a particular aspect of PCK" (Loughran et al., 2006, p.24). Pa-PeRs were written following implementation of the curriculum. Individual members identified a critical incident in their learning to teach teachers, and developed an initial draft to share with the group. Several rounds of feedback and revision were used to make our PCK explicit within these accounts. Throughout this process, we consulted additional data sources including the curriculum and assessments we developed for the program, teachers' pre and post tests, and teacher work (including summative evaluations of each of the 6 learning cycles).

Findings

Dinkelman (2003) suggests that self-study produces knowledge that practitioners can use to better understand their own immediate teaching contexts and situations as well as more generalizable knowledge that other educators can adapt to their own settings. The individual PaP-eRs are an articulation of the knowledge participants developed through the self study; for example, each of the PaP-eRs provides documentation of new insights, connections, and changing ideas about teaching teachers. However, examination of the Resource Folio as a whole provides useful insights into the nature, source, and development of PCK for teaching teachers.

Pa-PeR 1: Shadow Play

In the paper that follows, a mentee reflects on his experience using formative assessments with teachers. Through this, he highlights both his knowledge of assessment and instructional strategies.

> "The local puppet show will soon be putting a shadow play production of the Three Bears. Unfortunately, the three bear shaped puppets are all the same size. How will they ever be able to make Momma, Poppa, and Baby Bear using same sized puppets?"

Teachers were given this prompt in order to understand that they comprehend the factors that affect the size of a shadow. These factors are the distance between light source and object, the distance between light source and screen, and the distance between object and screen.

After teachers answered the prompt, there was a check out session. The "check-out" sessions were formative assessments we implemented throughout the learning cycle to make sure that teachers are on the way that we expect them to be. During check-out sessions, instructors were asking questions about what teachers learned, what they found, and how they were making sense of their data. We utilize probing questions to help expose flaws in their thinking, but also help them justify their answer with evidence.

After check-out session, I realized that some teachers focused on moving the light further or closer to change the size of the bear's shadow, while others simply moved the puppets closer or further from the light source. Nobody had chosen to change the position of screen. I was surprised that none of the teachers had chosen to change the position of screen. Right after this, I ran to the other room to tell this situation to my colleagues, to share my experience, and to get advice from them since this was my first teaching experience. They also had same situation and did not know how to deal with that. We got together with our mentor in the lunch to discuss this problem and how to deal with it. Below, I explain my experience while solving this problem in the light of our mentor advises.

What happened?	**My thinking**
To begin, I asked them to share their answers with each other.	I did want them to do so because in our discussion with our mentor, we decided to have teachers share their answer with their group members since each teacher solved the problem differently. Some of them chose moving the light source further or closer to the puppets and so on. Our mentor mentioned that seeing the different way to solve problem would help teachers understand the relationship more clearly.
When they shared their answers, teachers acknowledged “Oh. I didn’t think of that…” but also asked for their colleagues to show them that it could be done the way they explained in their drawing.	To me, this skepticism was a good thing-it seemed teachers were picking up on our own facilitation and habits of asking for evidence to support answers. (Our mentor was always pushing us to get teachers explain their ideas with evidence. By asking such questions *“Why do you think? Can you show me?* This was also what we want teachers to do with their students.
Nobody at this point mentioned moving the screen, so I asked them “Is there any other possible way to solve this problem?” Everyone started to discuss with their group members again.	Our mentor always told us about using driving questions to guide teachers. In this step, I used a driving question to push teachers’ thinking further. As I work with the teachers, I always wanted them to consider alternative explanations and solutions-this is important because it helped them learn from each other, as colleagues. Sometimes they offered explanations to others that resonate more than explanations that I gave them.
After discussing, teachers felt pretty sure that there were no other solutions. After that, I just gave them a clue “How about the screen?”	We had discussed this point in our discussion with our mentor. I had asked our mentor what if they didn’t recognize the effect of the position of the screen on the size of a shadow. Our mentor suggested us to give a clue to the teachers. She stated that giving clue to teachers would help to get their attentions to the clue and would enhance their curiosity so that they would want to try out. In this situation, I considered this suggestion and saw the effectiveness.
After my question, teachers started to try to change distance of the screen among object and light source and they realized that the distance between screen and object and the screen an light source affect the size of a shadow.	Our mentors was always telling us that the learning cycle is not a locked step—it doesn’t matter which phase you are, if you don’t feel comfortable with your explanation, it is OK to go back and explore again. This situation was a

	perfect situation for me to explain teachers this.
Teachers observed, and after that, they were able to revise their explanation. After they revised their explanations, I explained them as new evidence became available and existing explanations failed to explain, you went back and revise your explanations. Scientists also do that. They sometimes modify or reconceptualize their explanations in the light of new evidence.	It was an opportunity that teachers missed that the position of screen could be a factor which affects the size of a shadow for me to introduce them to the subjectivity of science. I didn't expect them to realize that scientific knowledge is subjected to change by themselves; for this reason, I did explain it in an explicit way.

Pa-PeR 2: ***Bouncing Around Ideas for Teaching the Law of Reflection***
In this paper, a mentee reflects on the dilemma she faced in helping teachers develop their understanding through hands-on activities. Through this, she highlights her knowledge of instructional strategies and learners.

When we designed the curriculum based on 5E learning cycle, we chose activities we felt best fit in terms of the purpose to be achieved at the end of each phase. For one of the 5E learning cycles, in order to introduce the concept of 'Law of reflection' we relied on an activity called *Target Tag activity*. For this activity, teachers were asked to record their ideas about on how they could hit a target with the help of flashlight and a mirror. The participants could either draw or write their illustrations for hitting the target. We expected participants to give various illustrations of bouncing light based on their experiences with bouncing objects, such as playing pool or ping-pong ball. After they have their rules noted down in their science journal the participants worked in pairs to hit various targets fixed all around the hallway. The participants tried to hit the target by positioning mirror and the flashlight so that the light reflected off the mirror and onto the target. The purpose of the activity was to help participants experience whether or not their pre-assumed rules worked. Also, the aim of activity was to help illustrate the law of refection of light, where incident angle is same as the reflected angle.

Although we as staff anticipated that by the end of the activity the participants' will be able to understand the law of reflection, some of pairs didn't arrive at the intended understanding that 'angle in is the same as angle out' for reflection of light. The main difficulty associated with the target-tag activity was that some of the participants were not able to visualize the position of the mirror and the flashlight and could not transfer that image in terms of angles associated with the ray of light. At this point, the other future teacher educators and I did not know what to do. I was not sure how to get participants to arrive at the right idea and it was at that point I felt panic in my nerves. I ran into my other colleague and told him about how and why I was feeling panicky. I told him that I did not know what I should do more to help the participants get to the right concept of reflection. To my surprise my colleague told me that he also faced the similar situation with the group of pairs he was monitoring. He was also worried about how to proceed without having the conclusions we were anticipating from the participants after their completion of the activity.

> He: "I don't think they got their rule figured out right, I am not sure what to say to them".
> Me: "Yes, you are right; I am also confused what to do next". Would it help if they discuss as a group what they found"?
> He: "I don't think so, some of them have got to the correct rule, but I am not sure that they understood the concept clearly".
> Me: "Well, then what should we do".
> He: "I don't know. We were not prepared for this tricky situation".

Me: “I have no idea either”.

With eye contact with us, our third colleague could guess that we are in dilemma. She came to us and told us “I know what is going on, I don’t know what to do next either”. She told the group of pairs whom she was monitoring did not realize the pattern of light falling in and out of the mirror. They could not get to the idea that the activity was not only meant to complete the task of hitting the target but also to understand the pattern in doing so. Some of them got swayed with the task of hitting all the targets and did not pay attention on how they aligned the mirror and the flashlight in doing so. We realized that without the results we expected our participants to arrive at, it would not make sense to proceed the next phase of the learning cycle. Also, we were confused to carry out any whole class discussion without the participants having their correct rule of light reflecting off the mirror. It was at this point when we all felt numbness in our nerves; we decided to talk to our mentor before it’s too late. Having understood teachers’ difficulty, our mentor came up with the idea of another activity which was more visual and helped illustrate the law of reflection more clearly. She went back in the supply room and brought out several bouncing balls. She had us form a line parallel to the wall, and then she asked us to pass the ball to one another by bouncing the ball off of the wall. Each time, she had us note where the ball struck the wall. Following this, we drew an imaginary line from the bouncer, to the wall, to the catcher. That served as an analogy for the path of light rays as they reflect off the mirror after striking its surface. This mentored experience gave us confidence to carry out the activity with small groups of teachers on our own. As we did this activity with teachers, it helped them to visualize how different angles were adjusted for different cases in delivering the ball to the catchers respectively. Hence by visualizing the ball the participants were able to formulate the correct rule for reflection- angle in is same as angle out. Intuitively, teachers knew where to aim the ball to make it get to the intended receiver. Retracing the path they threw the ball enabled them to visualize the angles at which it struck the wall and bounced.

One thing this experience emphasized for me is that while planning is important, things won’t always work out as you plan. This is due to the fact that individuals differ in the way they perceive things and also in their learning styles. While taking into consideration the individual differences in the classroom, the instructors need to be flexible in terms of introducing new activities and analogies which can improve conceptual understanding. Instructors need to change their plans accordingly, and for that they need to draw on their own PCK and select appropriate activities from their repertoire. This experience helped me to develop my own PCK, and to understand where flexibility is important. I now have a new instructional strategy in my repertoire for teaching the law of reflection. Furthermore, I can understand how this particular representation may be stronger than others and vice versa.

Below is the table which shows the strengths and weaknesses associated with the two activities.

Activity	Strengths	Weaknesses
Target tag activity	The activity allows learners to work in pairs and explore their ideas together. The activity is fun and engaging—it provides a challenge that is not too difficult. Drawing diagrams of how targets were hit can help learners understand how light reflects from mirror.	The activity is abstract in terms of the positioning of mirror and flashlight—learners might not notice exact positions and record these accurately. It is difficult to associate the activity with angles. It is difficult to visualize the position of mirror and flashlight and associate rays of light travelling in

	Flashlights are familiar material, and one that requires little instruction or safety precautions. Targets are easy and inexpensively made The activity takes little time to set up, do, and clean up Teams can tackle this challenge with little teacher supervision, initially	and out.
Bouncing ball activity	Intuitively each individual understands how it works. Kids can visualize the path of ball and associate them to rays of light, thus transferring example of real life to context of reflection. Concept of angle in is same as angle out could be achieved clearly as activity is visual. Activity could be carried out in small groups and its fun as kids enjoy playing with balls. Balls are inexpensive	Balls could be identified as 'photons' thus it is difficult to associate both particle and wave nature of light with this activity. With younger learners, teacher supervision would be needed to ensure that it's more than just play-specific lines of questioning should be pursued

PaP-eR 3: How We See

In this paper, a mentee reflects on the outcomes of an assessment she designed for the curriculum. Through this, she highlights important insights related to her knowledge of learners and knowledge of assessment.

Using black construction paper and white chalk, draw what you would see:

- At nighttime in a city
- At nighttime in a cave

At the evaluation phase of the learning cycle *How We See*, teachers were asked to draw pictures of nighttime of a city and nighttime of a cave on a sheet of black paper with white chalk. This assessment was intended to evaluate teachers understanding of the main idea of the lesson, "if there is no light, you cannot see anything." For nighttime in a city, I expected that teachers would draw some light sources and typical features of city such as cars and buildings on their drawings. For nighttime in a cave, I expected blank paper with no drawing. However, after I collected teachers' responses, I was quite surprised with their various drawings of nighttime in a cave. I said to myself, "What are they doing? What was the problem?" Teachers' drawings of nighttime in a city seemed to have no problems, but nighttime in a cave was illustrated in various ways. I expected that teachers would have no problems to do this task because they have learned that they cannot see anything when there is no light through the learning cycle. I also believed that the direction of the task was clear.

After I looked over teachers' drawing I had two opposite feelings: satisfactory and concerning. I was very pleased with teachers' answers for *nighttime in a city.* They draw streetlights as light sources and drew buildings and cars which are typical features of a city. However, I was disappointed with their drawings of *nighttime in a cave.* I expected that they would not draw anything on this part, but some of them drew outlines or detailed picture of a cave, because I expected that all the teachers could answer correctly. Because of my high expectation, my disappointment got doubled. At one of the afternoon sessions, I could have a chance to look over and discuss teachers' drawings of nighttime in a city and a cave with our mentor, Dr. Hanuscin.

> **Eun:** Dr. Hanuscin, I am really disappointed with some of the teachers' drawings. I expected that all the teachers could answer correctly, but some of them did not.
>
> **Dr. H:** Does this mean that they don't understand? I also think that it is interesting that some of them showed such different responses. How would you like to categorize their answers?
>
> **Eun:** Actually, majority of them did not draw anything on this part. So, this could be the first group. A few of them drew only outlines of inside of a cave. This is the second group. A few of them drew detailed description of inside of a cave. This could be the third group. Interestingly, a couple of them drew outside of a cave and added light sources on the picture. This is the fourth group.
>
> **Dr. H:** Can you explain what the pictures of each group are representing? It is important to speculate why teachers gave those responses or answers after eliciting their hidden thoughts. Especially at the evaluation phase, teachers' responses can be considered as their feedback given onto your instruction. It will be very valuable information for you to improve your instructions.
>
> **Eun:** I think the first group seems to understand what we intended to teach correctly. I feel comfortable that they understood what they were supposed to do, as well as the concepts. They did not draw anything because they understood that there is no light source inside of a cave in nighttime and they could not see anything. I am still glad that majority of them showed their correct understanding of "no light, no sight".
>
> **Dr. H:** What do you think about the second group? What is the difference between the second group and the third group since both groups drew pictures on that part?
>
> **Eun:** I think both groups didn't seem to understand that they cannot see anything when there is no light. They still kept their misconceptions that they had before the instruction: you can see the object or a faint outline of the object after your eyes adjust to the darkness. It is frustrating. I think, this means that I did not plan and teach well enough.
>
> **Dr. H:** Why do you think they still kept the misconception?
>
> **Eun:** They did not draw any light sources on their picture, but they showed that they could see outlines or details of a cave. I am not sure that they did not answer there is no light source in a cave. They just applied their knowledge from everyday experience into doing this task. If they had a chance to visit a cave, there must be a light source during daytime for example; sunlight or flashlight and they might see outlines or details of a cave. I think they failed to generalize their learning through this learning cycle to a new setting.
>
> **Dr. H:** It could be a reason. I think you can think their responses from a different view. Have you thought that directions in the task might be a reason? I think the direction might not be sufficient enough to explain conditions of each task. So teachers could interpret the direction on their own way. They just assumed that there is a light source or misinterpreted the direction as drawing a cave not drawing what they would see IN a cave.

> **Eun:** You mean that giving specific and explicit direction about the task will reduce unexpected responses from students? Yes, I agree with you. If we gave them explicit direction about light condition (no light), the direction itself could be a cue for them to think about the relationship between light and sight and generalize their learning. It is more hopeful if it is because of insufficient information on the direction not because of their misconception. We'd better talk to these two groups of teachers to identify what was the problem to clarify the reason.
>
> **Dr. H:** Yes, it is also related to drawings of the fourth group. Why do you think the fourth group of teachers draw outside of a cave and added a light source on their pictures? Do you think it has something to do with their learning or directions of the task?
>
> **Eun:** As far as they added a light source on their pictures, I'd like to assume that they understand that they need to have a light source to see the outside of a cave. I think we need to give them more explicit and clear directions.
>
> **Dr. H:** Based on our discussion, how would you like to modify the directions of the task?
>
> **Eun**: In terms of directions, we'd better ask them to draw inside of a cave during nighttime without any light source or ask them to draw what they would see in cave nighttime and explain their drawings. By asking them to explain their drawings, I can figure it out reasons of their understandings and misunderstandings.

Pa-PeR 4: Focusing on the Right Ideas

In this paper, the mentor reflects on working with mentees to develop a curriculum for teachers, and the issue of what content is important to address for teachers and their students.

> "If we really want them to understand the source of light, then we need to discuss thermonuclear reactions…"

This is a statement I overheard one of the teacher participants making to his small group as I circulated around the room during an activity related to identifying sources of light. Teachers had been presented with several drawings of different everyday situations (e.g., a person standing underneath a streetlight) and had been asked to consider what the person in the picture could see and how they were able to see.

I have to admit, I was a bit irritated—what was this person trying to do? Show off his knowledge of science? Knowing that many of the teachers participating in the program come to this workshop because they don't feel confident about their science knowledge, I was concerned about how his comment would affect his group members. Of course, as I began to think more about why his comment evoked such a strong emotional reaction in me, I realized that I had taken his comment as a criticism of the curriculum itself, an indication that we weren't really focusing on the 'right' ideas.

In developing a curriculum for teachers, professional developers should be providing opportunities for teachers to learn at their level—not simply participate in student activities. Yet, even though they may be adults, teachers often hold many of the same misconceptions as students. For the professional developer, this poses a dilemma—how to design a curriculum that meets teachers' needs in terms of understanding the fundamental ideas about the concepts, while still challenging them at an appropriate level. Because I had worked with my mentees to develop the curriculum, I brought this instance to their attention and asked, *Should* we be addressing thermonuclear reactions, as the teacher commented? What evidence do we have that our curriculum was appropriate to meeting teachers' needs? We had consulted both student curricula and teacher curriculum materials in developing our workshop materials—yet, were we off the mark?

One piece of evidence the group provided that our curriculum was focusing on the 'right' ideas was the pretest—We designed this test to assess mastery of the concepts on which the curriculum focused. There were multiple questions for each concept, so that we might have a more robust understanding of teachers' ideas. None of the teachers in the program mastered this pretest—indeed, even those who answered one item for a particular concept correctly often missed the additional item(s) for that same concept. To us, that suggested value in teachers revisiting their ideas. Nonetheless, a number of teachers did demonstrate mastery of some concepts beforehand—thus, it was still necessary for us to move beyond what they know to deepen their understanding. One unique feature of the curriculum we designed that allows us to do that is the provision of "check-outs", or informal assessment dialogues with staff. These interactions provided us opportunities to pose questions that can push teachers' thinking further, helping them refine their conceptual models. Through this discourse, we encouraged teachers to consider alternative explanations, justify their thinking, and find additional ways to apply the concepts to everyday life. Each of these skills, in turn, can help them develop a variety of ways to present and explain concepts to their students.

A common thread in our "check-outs," is developing evidence-based explanations. We expect teacher to provide explanations to us based on the evidence they've gathered, not rely on hearsay (things they've read or heard). Thermonuclear reactions are not something we were exploring firsthand (for obvious reasons), and so my reaction to this teacher bringing that up actually stemmed from my vigilance in wanting teachers to focus on their own observations and evidence. To me, it does gets at the fundamental notion of what it means to understand- To know not because somebody else told you, or you read about it, but because you have constructed that understanding for yourself. Our curriculum for teachers focuses on providing firsthand explorations through which they can construct an understanding of the fundamental concepts of light. We agreed, as a group, that we want teachers to be able to answer the question, "How do you know?" and for that answer <u>not</u> to be, "Because you told me."

Discussion

While a growing body of research has been devoted to the construct of PCK and how teachers' expertise develops, there is currently a lack of studies of teacher educators' expertise on how to prepare science teachers to teach subject matter (van Driel & Berry, 2010). Furthermore, little is known about the means through which doctoral students (future teacher educators) develop their knowledge in this regard (Abell, et al. 2009). The present study addresses this gap in the literature by providing a rich portrayal of our PCK in action in a way that is accessible to other teacher educators and researchers.

The overarching goal of our self-study revolved around articulating and representing our PCK for teaching teachers the topic of light. The CoRe we constructed documents our PCK for five big ideas related to this topic. Within each idea, the CoRe addresses our knowledge of learners, curriculum, instruction, and assessment. The Pa-PeRs provide an illustration of this knowledge enacted in practice. By looking across each of the Pa-PeRs and examining the Resource Folio as a whole, we are able to make several assertions about both the process of self-study and the impact of mentoring on our developing PCK. First, having an experienced other or "mentor" during the process of self-study to discuss, reflect, and debrief the experience is critical in terms of drawing useful insights relevant to developing one's PCK; the perspective of the expert often differs from the novice, and prompting questions from a mentor can help mentees make the tacit explicit within their practice. Second, self-study provides a systematic means through which novice teacher educators can identify and take steps to address gaps in their PCK for teaching teachers. The CoRe itself provides a means for making these gaps visible. In the sections that follow, we consider the development of our PCK in terms of each of the component knowledge bases in Magnusson et al's model. Additionally, we discuss how the mentored internship experience influenced the development of our topic-specific PCK for light, as well as our discipline-specific PCK for teaching science teachers.

Knowledge of Teachers as Learners

Knowledge of learners (in this case teachers) includes understanding of the prerequisite knowledge and skills learners need, areas of difficulty, common errors, misconceptions, and connections to common experiences. Furthermore, it involves understanding of developmentally appropriate practices—in our case, understanding teachers as adult learners.

Knowledge of teachers' knowledge

From the process of developing CoRe for each learning cycle, we searched common misconceptions and other difficulties we could encounter while our teaching because teachers often hold many of the same misconceptions as students. We expected that teachers have misconceptions such as "you can see the object or a faint outline of the object after your eyes adjust to the darkness." Our knowledge of teachers' misconceptions had been carefully taken into account in the process of developing activities, assessments and pre- and post-test questions. In spite of careful preparation based on our knowledge of learners (teachers), when an assessment did not elicit teachers' learning as successfully as planned, a novice teacher educator became frustrated and perplexed (Pa-PeR 3). The mentor guided the mentee to see the situation from different perspective, and to better understand the reasons for teachers' specific difficulties.

Knowledge of teachers' role-transition as learners

Many teachers who participated in this workshop came because they didn't feel confident about their science knowledge and how to teach science to their students. As learners, they identified a gap in their own knowledge. Yet, as teachers, they often feel the need to be the "expert"—thus, they experience conflicts in their role as learner and teacher. While drawing on teachers' classroom experience and expertise is important, assisting teachers in transitioning into the role of learner is critical to the success of the professional development. For this purpose, as mentioned in Pa-Per 4, we build our curriculum in a way that provides firsthand explorations so that teachers construct robust understandings of the fundamental concepts of light. In order to better help teachers' role-transition, our mentor suggested to add "check-out" at the end of learning cycle. As illustrated in Pa-Per 1, check-out questions were designed to confirm teachers' clear understanding without intimidating them. When a mentee found out teachers' insufficient understanding of relationship between light and shadow formation, our mentor recommended us to give a clue to teachers. By doing this, we could give teachers chance to explore more as learners without challenging their identity as teacher.

Knowledge of Curriculum

Knowledge of curriculum relates to an understanding of mandated goals and objectives, an awareness of what students have learned in previous years and what they will learn in later years, and the various curricular programs and supplementary instructional materials that can be utilized to teach a particular topic (Magnusson et al., 1999). Working together as mentor/mentees to develop the CoRe provided a structured and guided opportunity to develop our knowledge of curriculum. By identifying relevant K6 standards (Missouri Grade Level Expectations, National Science Education Standards, and Benchmarks for Science Literacy), mentees were able to develop a broader understanding of how concepts and ideas related to the topic of light are addressed across the grade levels. In terms of curricular knowledge for teaching teachers, this helped them understand the foundational knowledge necessary for K6 teachers to help students meet these goals. As illustrated in Pa-PeR 4, mentees gained insight into deciding on the 'right ideas' to address in a curriculum for teachers. Through examining both student curricular materials (e.g., *Science and Technology for Children)* and teacher curricular materials (e.g., *Physics by Inquiry, Shedding Light on Science*) the distinction between teaching light to elementary students and to adult learners became more clear. As illustrated in the CoRe, our attention became focused on not just the curriculum itself, but also the rationale behind the curriculum and our instructional decisions.

Knowledge of Instructional Strategies

For achieving the instructional goals, the content needs to be organized into learning activities consistent with the skills and knowledge that the teachers are expected to acquire. This draws our attention to the fact that PCK is acknowledged as transferring subject matter knowledge to subject matter knowledge for teaching (Park & Oliver, 2007); in other words selecting appropriate instructional strategies for teaching. Knowledge of instructional strategies includes both subject specific strategies (e.g., the learning cycle) as well as topic-specific strategies. These can include representations (i.e., illustrations, example, models, analogies, etc.) as well as activities (i.e., problems, demonstrations, investigations, etc.).

Both the experience of writing CoRe and Pa-PeRs helped us develop knowledge of instructional strategies which is one of the important components of PCK. The initial process of constructing the CoRe helped us develop subject specific strategies such as inquiry based instruction and the 5E learning cycle; however, the reflective process of constructing Pa-PeRs helped us further refine our topic-specific PCK for light. Initially, we relied on some pre-existing activities and analogies suggested in curriculum materials and activities that had worked for our mentor. In practice, we realized that some of these activities (such as 'target tag' as illustrated in Pa-PeR 2) were not effective in achieving the desired outcome. Thus, alternative instructional strategies and representations were needed. Our mentor helped us expand our repertoire by suggesting additional analogies and activities that could connect to teachers' everyday experiences. By reflecting on our use of these strategies, we were able to further develop our PCK.

Knowledge of Assessment

Knowledge of assessment comprises knowledge of what to assess and methods for assessing it (Magnusson et al; 1999). That is to say, knowledge of assessment should include what to assess, how to assess it, and how to interpret the results. In this mentor-mentee relationship, we had multiple opportunities to practice both formative and summative assessment throughout the workshop such as check-out sessions, formative assessment prompts, tests, and so on. Each of these was a valuable experience to improve our knowledge of assessment.

Constructing the CoRe allowed us to collaboratively negotiate and identify the key learning outcomes to assess. In developing the curriculum, we drew on existing curriculum materials and assessments, our mentor's advice, and our own past teaching experience to devise both formative and summative assessment tasks. Though we were able to anticipate some responses to these assessments, we were nonetheless caught off guard on occasion as illustrated in Pa-PeR 1 and Pa-Per 3. In these instances, we we relied on each other as colleagues to interpret the outcomes of these assessments and to devise the next steps in instruction.

For example, in Pa-PeR 1, we used a check-out to assess teachers' understanding of relationship between light source, object, and screen and how does this relationship affect the size of a shadow. After keeping this aim in our mind, we designed our assessment prompt. We administered it to teachers and saw that they didn't understand the effect of screen on the size of a shadow. With the suggestions and directions of our mentor, we used our results of assessment to improve teachers' understandings. We went back to investigation part and had teachers further explore the effect of screen on the size of a shadow and revised their explanations.
As illustrated in Pa-PeR 3, summative assessments sometimes revealed teachers were not having a difficulty with the concept as much as a difficulty understanding our assessment. In this manner, we were able to interpret the results and refine our assessment strategies to more effectively elicit teachers' understanding.

Conclusions

Just as Appleton (2008) found that mentoring supports the development of elementary teachers' PCK for teaching science, we found mentoring to be an effective means for supporting the development of prospective teacher-educators' PCK. The particular mentoring relationship between the graduate students and faculty in this study reflected the three dimensions in Kochan's (2002) model. Specifically, both mentor and mentees were committed to working together and effectively communicating and resolving problems of practice (relational); the relationship was such that they held a common understanding of the purposes of the mentored internship and how it was intended to support their professional growth (reflective); and the relationship was founded on common values, mutual respect, and the expectation of benefits for both mentor and mentees (reciprocity). Our findings suggest that mentored internships provide an opportunity for prospective teacher educators to bridge the gap between knowledge they develop in their courses and their actual practice.

Implications

The internship experience utilized in our study is consistent with the model for preparing the next generation of science teacher educators described by Abell et al. (2009) in which doctoral students progressively take on more responsibility and independence in learning to teach teachers, and in doing so develop their PCK. The internship provides a viable means for making the preparation of teacher educators an explicit component of their doctoral study. Nonetheless, further research is needed to understand whether this type of mentorship might also produce similar results in other contexts (e.g., within a methods course versus a professional development program). On the basis of our experience, we suggest that, if doctoral student preparation is to be successful in developing students' PCK for teaching teachers, a major component of their program should focus on authentic experiences in which they can develop their PCK in practice. While there will always be a place for formal coursework and learning theory, this is and of itself is insufficient to promote robust PCK.

References

Abell, S.K., Park-Rogers, M. A., Hanuscin, D.L., Lee, M.H., Gagnon, M.J. (2009). Preparing the next generation fo science teacher educators: A model for developing PCK for teaching science teachers. *Journal of Science Teacher Education, 20*: 77-93.

Abell, S.K., & Volkmann, M.J. (2006). Seamless assessment: A guide for elementary and middle school teachers. Arlington, VA: NSTA Press.

Appleton, K. (2008). Developing science pedagogical content knowledge through mentoring elementary teachers. *Journal of Science Teacher Education, 19*, 523-545.

Bybee, R.W. 1997. *Achieving scientific literacy: From purposes to practices.* Portsmouth, NH: Heinemann.
Dinkelman, T. (2003). Self-study in teacher education: A means and ends tool for promoting reflective teaching. *Journal of Teacher Education, 54*(1), 6-18.
Grossman, P. L. (1990). The making of a teacher: Teacher knowledge and teacher education. New York: Teachers College Press.
LaBoskey, V. K. (2004). The methodology of self-study and its theoretical underpinnings. In J. Loughran, M. L. Hamilton, V. K. LaBoskey & T. Russell (Eds.), *International handbook of self-study of teaching and teacher education practices* (Vol. 12, pp. 817-869). Netherlands: Springer.
Loughran, J. (2005). Researching teaching about teaching: Self-study of teacher education practices. *Studying Teacher Education, 1*(1), 5-16.
Loughran, J. (2007). Researching teacher education practices: Responding to the challenges, demands and expectations of self-study. *Journal of Teacher Education, 58*(1), 12-20.
Loughran, J., Mulhall, P., & Berry, A. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. Rotterdam: Sense Publishers
Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Boston, MA: Kluwer.
Park, S., Oliver, J.S. (2007). Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education, 38,* 261-284.
Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.
van Driel, J. H. & Berry, A. K. (2010). Teaching about teaching science: What do science teacher educators do and why? Paper presented at the annual meeting of the National Association for Research on Science Teaching. Philadelphia, PA.