2017

Learning from Rookie Mistakes: Critical Incidents in Developing Pedagogical Content Knowledge for Teaching Science to Teachers

Suleyman Cite

Eun Lee

Deepika Menon

Deborah L. Hanuscin

Published in *Studying Teacher Education* 13:3 (2017), pp. 275–293; doi: 10.1080/17425964.2017.1366306

Submitted October 5, 2016; accepted April 17, 2017; published online August 24, 2017.

Learning from Rookie Mistakes: Critical Incidents in Developing Pedagogical Content Knowledge for Teaching Science to Teachers

Suleyman Cite,[1] Eun Lee,[2] Deepika Menon,[3] and Deborah L. Hanuscin[4]

1. University of Missouri, USA
2. Wisdom Center, Seoul, Korea
3. Towson University, USA
4. Western Washington University, USA

Corresponding author – Deborah L. Hanuscin, email hanuscind@missouri.edu

Abstract

While there is a growing literature focused on doctoral preparation for teaching about science teaching, rarely have recommendations extended to preparation for teaching science content to teachers. We three doctoral students employ self-study as a research methodology to investigate our developing pedagogical content knowledge for teaching science to teachers during a mentored internship in an elementary teacher professional development program. With our mentor, we examine critical incidents in the experience that supported new insights about teaching teachers and about ways in which beginning teacher educators need to develop their existing pedagogical content knowledge for teaching science to *students* in order to teach science effectively to *teachers*. We emphasize ways in which doctoral internships can support this learning and how our respective cultures shaped our interactions with and perceptions of teachers as learners.

Aprendiendo de los errores de principiante: incidentes críticos en el desarrollo de conocimiento pedagógico del contenido para enseñar ciencias a profesores

Mientras que hay cada vez más literatura que se enfoca en la preparación doctoral para enseñar acerca de la enseñanza de las ciencias, rara vez se encuentran recomendaciones para enseñar contenidos de ciencia a profesores. En nuestro grupo de tres estudiantes doctorales utilizamos el self-study como metodología de investigación para estudiar nuestro creciente conocimiento pedagógico del contenido para enseñar ciencias a un grupo de profesores durante una pasantía de mentorías en un programa de perfeccionamiento para docentes de primaria. Con nuestro mentor, examinamos incidentes críticos en la experiencia que dieron lugar a nuevas comprensiones respecto a enseñar a profesores y acerca de modos en que los formadores principiantes de docentes necesitan desarrollar su conocimiento pedagógico del contenido para enseñar ciencias a *estudiantes*, para así poder enseñar ciencias de manera efectiva a otros *profesores*. Enfatizamos los modos en que las pasantías doctorales pueden ayudar a este tipo de aprendizaje y cómo nuestras respectivas culturas moldearon nuestras percepciones e interacciones con los docentes en tanto estudiantes.

Keywords: pedagogical content knowledge, teacher education, doctoral programs, mentoring

Palabras clave: conocimiento pedagógico del contenido, formación docente, programas doctorales, mentoría

Teachers require specialized knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners, or what is known as pedagogical content knowledge (PCK) (Shulman, 1987). A particular challenge for science teacher educators, particularly at the elementary level, is that the teachers often have weak understanding of science (Fulp, 2002), which is prerequisite to developing PCK (Loughran, Mulhall, & Berry, 2006; van Driel, Verloop, & de Vos, 1998). Weak content knowledge impacts teachers' ability to identify common misconceptions underlying student work and to analyze trade-offs between various instructional decisions (Daehler, Heller, & Wong, 2015; Daehler & Shinohara, 2001). From this, it follows that, in addition to developing knowledge and skills for teaching about *teaching science*, knowledge and skills for teaching science to teachers would be important for teacher educators to develop.

Alhough prospective teachers typically receive science content instruction from scientists, it is not uncommon for teacher educators to teach science courses (Hart & Mars, 2009) or be involved in designing and conducting content-focused professional development for inservice science teachers. Just as beginning teacher educators have documented that the knowledge and skills of a K–12 teacher do not translate easily to teaching *about teaching* (Bullock, 2009; Cooper, Loughran, & Berry, 2015), we argue that knowledge and skills for teaching science to *K–12 students* does not translate directly to the teaching of science to *teachers*.

Wilson emphasized that it is rare for beginning teacher educators to "have opportunities to learn to teach teachers in structured and scholarly apprenticeships; instead they are thrown into the practice of teacher education" (2006, p. 315). While there is growing recognition that doctoral programs should provide opportunities "to observe, practice, and reflect on the pedagogical knowledge necessary to instruct future science teachers" (Abell, Rogers, Hanuscin, Lee, & Gagnon, 2009, p. 77), the recommendations focus almost exclusively on preparation for *teaching about science teaching*, as opposed to *teaching science content*.

Self-studies by teacher educators have documented the difficulty of transitioning from teacher to teacher educator (Wood & Borg, 2010), the importance of support for doctoral students as they make this transition (Wiebke & Park Rogers, 2014), and how doctoral internships can provide this support (Vogel & Bartlett, 2013). While these studies provide insights into teaching *about teaching*, as a field we know very little about how beginning teacher educators navigate the transition to teaching *about content*. Our self-study is a foray into that uncharted territory to examine the experiences of three doctoral students during an internship in a professional development program for elementary teachers. The study is a collaborative research project in four voices: Suleyman, a doctoral student from Turkey; Eun, a doctoral student from Korea; Deepika, a doctoral student from India; and their mentor, Dr H., a science teacher educator jointly appointed in education and science.

Purpose of the Study

Engaging in self-study can help individuals develop their own PCK and become better teacher educators both in *teaching about teaching* (Faikhamta & Clarke, 2013; Osmond & Goodnough, 2011) and *teaching science content* to prospective teachers (Nyamupangedengu, 2016). As such, we believed self-study would help us identify gaps in our knowledge and take steps to address them. Self-study can help educators address problems in their own teaching contexts and can produce knowledge that "teacher educators in other settings can draw on and adapt to their own teacher education settings" (Dinkelman, 2003, p. 11). Thus this was an opportunity to shed light on the knowledge necessary to teach science to K–12 *teachers*, rather than K–12 students, and to consider how doctoral students' development as teacher educators might be supported through internship experiences. The questions guiding our self-study were:

(1) What critical incidents do we (novice teacher educators) experience when teaching science to elementary teachers, and how do these inform our developing PCK?
(2) In what ways do we need to develop our existing PCK for teaching science to elementary *students* in order to effectively teach science to elementary *teachers*?

Theoretical Framework: Pedagogical Content Knowledge

Shulman (1987) first introduced PCK as a fundamental knowledge base for teaching. PCK makes possible the transformation of disciplinary content into forms that are accessible and attainable by students, and involves a 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) and has been applied to the knowledge of teacher educators. As Abell et al. (2009) describe:

> A science teacher educator's PCK includes his/her knowledge about curriculum, instruction, and assessment for teaching science methods courses and supervising

> field experiences, as well as his/her knowledge about preservice teachers and orientations to teaching science teachers . . . The science teacher educator should understand the points of resistance that prospective teachers might experience when learning about science teaching. Furthermore, the science teacher educator should know strategies for helping future teachers confront their naïve conceptions of science teaching and learning and find suitable alternative views. (p. 79)

While this notion of PCK attends to knowledge teacher educators need for *teaching about teaching science*, we argue that PCK can also be applied to considering the knowledge teacher educators need for *teaching science to teachers* and that this PCK is different from that needed for teaching science to K–12 students.

PCK is understood to be developed through practice and with experience teaching (Magnusson et al., 1999); however, the literature also documents a variety of ways in which PCK development can be supported. For preservice and inservice teachers, these include reflection on and in teaching (Abell, 1997); engaging in cycles of planning, teaching, and reflection (Zembal-Saul, Blumenfeld, & Krajcik, 2000); mentoring (Appleton, 2008); and modeling of teaching practice (Abell, 2008). Sources of PCK *for teacher educators* include experiences teaching science K–12 (Berry & van Driel, 2012; Smith, 2000), experiences teaching in a teacher education program (Abell et al., 2009), graduate coursework (Abell et al., 2009), research literature (Smith, 2000), self-study (Demirdogen, Aydin, & Tarkin, 2015; Faikhamta & Clarke, 2013; Wiebke & Park Rogers, 2014), and mentoring (Abell et al., 2009).

Recent literature (Berry, Friedrichsen, & Loughran, 2015) emphasizes that an individual's PCK draws on the formal knowledge bases of the profession (assessment knowledge, pedagogical knowledge, content knowledge, curricular knowledge, and knowledge of students) and topic-specific professional knowledge, each of which is publicly codified and available to practitioners. This is distinct from personal PCK, which is less visible and includes the "*knowledge* of and *reasoning* behind, and *planning* for teaching a particular *topic* in a particular way for a particular *purpose* to particular *students* for enhanced *student outcomes*" (Gess-Newsome, 2015). A further distinction is made between personal PCK *knowledge* and personal PCK and *skill*, which occurs in the act of teaching. This latter distinction is important because possessing the knowledge of what to do in a particular teaching situation does not mean one would be able to do that effectively.

The Research Context

The Internship Experience

To avoid the sink-or-swim approach to preparing future teacher educators, the doctoral program in science education at our institution requires all candidates to complete a teacher education and professional development internship (Abell et al., 2009). The internship experience reflects an inquiry stance as described by Cochran-Smith and Lytle:

> Taking an inquiry stance means teachers and student teachers working within inquiry communities to generate local knowledge, envision and theorize their practice, and interpret and interrogate the theory and research of others (1999, p. 289).

Doctoral students are free to arrange internships based on their unique interests, experiences, and needs. In this case, we identified the need to develop our ability to teach science effectively to teachers. We chose to intern with a faculty member (Dr H.) who was offering professional development to elementary teachers.

Quality Elementary Science Teaching (QuEST) Program

The QuEST program provides professional development to elementary teachers via a two-week summer institute and academic year follow-up sessions. Participating teachers take the role of learners in week one of the summer institute. Morning sessions focus on science content, while afternoon sessions focus on science pedagogy. The two are complementary in that content instruction aligns with, and models, the pedagogy teachers learn in the afternoon sessions. In week two, participants shift back into the role of teacher as they design and implement a week-long half-day science program for elementary students. This practicum experience allows teachers to practice implementing what they learned and develop expertise in a collaborative environment, prior to returning to their own classrooms.

As graduate student interns, we participated fully in the planning and enactment of science content instruction in week one. Our decision to focus on the teaching of science content was intentional for several reasons. Given that physics is a recognized area of weakness among elementary teachers (Fulp, 2002), we believed that strengthening our topic-specific PCK would be important to our future work with elementary teachers. Additionally, we believed that practice implementing pedagogies learned in our graduate study would be important for developing expertise before teaching these pedagogies to teachers. Dr H. acknowledged the importance of being able to practice what we preach, and as their mentor Dr H. served as a critical friend to support us in doing the same.

Content Instruction: Learning about Light

The internship spanned seven months, beginning with a semester-long curriculum planning experience and culminating in enactment of the curriculum during the summer institute. In this way, it supported both developing our PCK (knowledge) and PCK and skills (enactment) (Gess-Newsome, 2015). While some programs instruct teachers using science curricula intended for elementary learners, there is widespread recognition that the needs of teachers are different from the needs of science majors or other non-majors (Duran, McArthur, & Hook, 2004; McDermott, 1990; McDermott, Shaffer, & Constantinou, 2000). Accordingly, the science curricula developed and utilized in the QuEST program are intentionally designed (1) to meet teachers' needs, interest, and abilities as adult learners; (2) to emphasize content teachers are expected to teach; and (3) to model the pedagogical approaches teachers learn in the professional development program. The latter includes the 5E Learning Cycle (Bybee, 1997). In the year the internship occurred, the topic of study was light.

To develop the curriculum, we met weekly with our mentor to review research literature on teaching and learning about light (e.g., Anderson & Smith, 1986; Brown, Cocking, & Bransford, 2000; Lederman & Abell, 2014; Shapiro, 1989; Smith & Neale, 1989), standards and reform documents (AAAS, 1990; NGSS Lead States, 2013; NRC, 1996), pedagogical approaches (Bybee et al., 2006), and existing curriculum materials and assessments for elementary students (such as STC and FOSS) and teachers (e.g. McDermott, 1995).

Research Design

Self-study (Loughran, 2005, 2007) builds upon the traditions of reflective practice, action research, and practitioner research. This form of inquiry provides in-depth descriptions that illuminate the complexities of teaching and articulate the "wisdom of practice" (Shulman & Hutchings, 2004) It is through reflection *on* action and reflection *in* action (Schon, 1983) that personal PCK is made explicit. Therefore, self-study provides an appropriate means to articulate, capture, and critically examine our PCK for teaching teachers.

Participant Collaborators

Consistent with self-study, ours was a collaborative endeavor. Suleyman is a doctoral student from Turkey, who had completed a bachelor's degree in middle school science in his native country, and a master's degree in the USA in science education. His teaching experiences were limited to student teaching experiences in Turkey and science outreach experiences in the USA. This was his first experience teaching teachers. Eun was a doctoral student with three years of teaching experience in Korea. While she had earned a master's degree in elementary education, this was also her first experience with professional development for elementary teachers in science. Deepika was then a doctoral student from India, where she had completed bachelor's and master's degrees in science education. Her background included five years of teaching grades 5–6 and 11–12 in India. While she had limited prior experience working with teachers through teaching assistantships, this was the first time she was fully involved in curriculum design and implementation in a professional development setting. Their mentor (Dr H.) is a former elementary teacher and current faculty member in science education with 21 years of experience providing professional development to teachers. She served as the director of the QuEST program.

Data Sources and Analysis

We used multiple data sources to elicit, represent, and document growth in our PCK knowledge and skills throughout the experience. Because "effective self-study requires a commitment to checking data and interpretations with others" (Loughran & Northfield, 1998, p. 2), our analysis of the data was a collaborative and ongoing process.

PCK Knowledge

To access and document our developing personal PCK, we utilized the Content Representation Tool (CoRe) (Loughran et al., 2006), which has been used with success in teacher education to document and support the development of preservice teachers' PCK (Hume & Berry, 2011). 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 specific teaching procedures and reasons for using them. We modified several of the categories of the CoRe slightly, in order to accommodate our focus on teaching teachers. For example, 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." The CoRes provided a basis for developing our curriculum materials to use with teachers. Thus, additional data sources documenting our PCK knowledge included the lessons and accompanying instructor facilitation notes we developed, and notes from discussions at our weekly meetings.

PCK Knowledge and Skills

As we enacted the curriculum, conversations with our peers and mentor were important. We met both before and after the 3-h teaching sessions to engage in dialogue as critical friends (Samaras & Freese, 2006). We provided support to one another as we identified problems of practice and encountered difficulties in putting our knowledge into practice. We took note of specific issues that we encountered during teaching in our instructor notebooks, and documented important ideas generated in our conversations in our personal reflective journals. The series of CoRes we constructed during our curriculum development experience was further annotated and adapted throughout the enactment stage of the internship experience as well with our new insights.

At the end of our implementation of the curriculum, we analyzed our data to generate Pedagogical and Professional Experience Repertoires (PaP-eRs). A PaP-eR is a "narrative account of a teacher's PCK that highlights a particular piece, or aspect, of science content to be taught" and "is designed purposefully to unpack a teacher's thinking about a particular aspect of PCK in that given content" (Loughran et al., 2006, p. 24). In a PaP-eR, an "episode is reconstructed in a communicable form that is intended to carry the meaning that is not always explicitly embedded in typical descriptions of teaching practice" (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001, p. 302).

The focus of our analyses was on identifying critical incidents that led to our new insights about teaching science to teachers. Tripp (1993) described critical incidents as events that arise in practice from the way that teachers look at a situation and interpret its significance. Growth in knowledge for teaching comes about when reflection on critical incidents involves challenge to and critique of one's self and professional values, which can in turn lead to changes in practice. Thus critical incidents can play a role in developing PCK as teachers reflect on their experiences.

We first read and reread the various iterations of the CoRes to note areas of growth in our PCK. We then individually reviewed our reflective notes to identify critical incidents that supported this growth. We discussed the critical incidents that each of us identified, using feedback from the group to explore what was personally meaningful in our learning to teach teachers and why. Next, each of us developed an initial draft PaP-eR to share with the group. Several rounds of feedback and revision were used to make elements of our developing PCK and insights about teaching teachers explicit within these accounts. Our mentor posed questions that pushed us to make our underlying reasoning explicit, such as *What assumptions were you making about teachers?* and *Why do you think you felt this way when this happened?* Throughout this process, we consulted additional data sources, including the curriculum and assessments we developed for the program, our notes and reflections, and teacher work samples to enrich our accounts.

Findings

The individual PaP-eRs we generated are an articulation of the knowledge we developed through self-study and a way for us to share that knowledge with others. PaP-eRs do not follow a single format or structure but reflect the unique knowledge, experience, and insights of the author, enhanced through interactions with others (Loughran et al., 2006). In this sense, the individual papers, taken together, provide a more robust understanding of different aspects of PCK. The PaP-eRs provide an answer to our first guiding question regarding critical incidents in our experience and the insights we gained from them. Examination of the set of PaP-eRs as a whole provides useful insights into our second research question, regarding how the PCK we developed for teaching science to teachers goes beyond the PCK we need to teach science to K–12 students. In the sections that follow, we present the series of PaP-eRs we generated, then draw insights about our developing PCK.

Analysis of Critical Incidents

PaP-eR 1: When the Teacher is the Student (Suleyman's Story)

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

We provided this prompt in order to help teachers consider the factors that affect the size of a shadow, specifically the distance between a light source and an object, the distance between a light source and the screen, and the distance between an object and the screen.

After teachers discussed the prompt, they used materials to explore their preconceptions. The curriculum then directed teachers to check with an instructor. The check-out sessions were formative assessments implemented throughout the curriculum to make sure that teachers were progressing in their understanding. During check-outs, instructors asked questions about what teachers observed and how they were making sense of their data. We utilized probing questions to help expose flaws in their thinking and to encourage teachers to justify their answers with evidence.

During one check-out, I realized that some teachers focused on moving the light farther or closer to change the size of the bear puppets' shadows, while others simply moved the puppets closer or farther from the light source. Nobody had chosen to change the position of the screen, which surprised me. Based on my limited elementary teaching experience, I had not anticipated this; I had expected that the teachers would explore all three factors. I had made assumptions about the knowledge teachers would already possess about light; I was still viewing them as experts and myself as a novice.

I knew I did not want to just give teachers the answer; as I had learned in my coursework, I needed to guide teachers to realize the position of the screen was also a factor. However, I was at a loss for how to do that. I sought advice from the other interns beause this was my first experience teaching teachers. They were also hesitant about how to respond. We felt discomfort with the idea of correcting *teachers.* We got together with our mentor 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's advice.

This incident was critical to my developing PCK because it helped me realize the importance of modeling the pedagogy we are teaching to teachers. The experience provided me opportunities to address gaps between my knowledge and my skills for implementing the 5E learning cycle, effective questioning, and teaching about the nature of science. Using these strategies effectively was important, since I noticed that teachers were modeling their own behavior after mine (Table 1).

Table 1. Reflection on my pedagogical moves and motives

What happened?	My thinking
To begin, I asked teachers to share their answers with each other	Following our discussion with our mentor, we decided to have teachers share their ideas with their group members since each teacher solved the problem differently. Some of them chose moving the light source farther or closer to the puppets and vice versa. Our mentor mentioned that seeing the different ways to solve problem would help teachers understand the relationship more clearly but would also point out that there were multiple possible solutions.
When they shared their answers, teachers acknowledged "Oh. I didn't think of that . . ." but also asked for their colleagues to show them (physically) 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 always reminding us to encourage teachers to explain their ideas with evidence by asking such questions as *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 "Do you think there is any other possible way to solve this problem?" Everyone started to discuss with their group members again.	Our mentor reiterated the importance of using questions to guide teachers. 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 resonated more than the explanations that I gave them. I could build from their recognition of multiple solutions to encourage them to think about additional ways to change the size of the shadow, possibly moving the screen.
Teachers felt pretty sure that there were no other solutions. I then asked more specifically "What would happen if you moved the screen?"	We had anticipated this in our discussion with our mentor. While I hoped that they would have come up with the position of the screen as another factor, we thought through the possibility that they might not. Our mentor suggested that, in situations like this, we use action-oriented questions. She stated that this type of question ("What would happen if . . . ?") could be answered only by trying it out. Thus we could encourage further exploration. In this situation, I considered the suggestion and saw its effectiveness.
After my question, teachers started to explored further and realized that this also affected the size of a shadow.	Our mentor was always telling us that the learning cycle is not a lock-step process; it doesn't matter which phase you are doing. If you don't feel comfortable with your explanation, it is OK to go back and explore again. This situation was a perfect example of where it was appropriate to ask teachers to go back and explore, and it provided an example for me to help teachers understand this as well, and when they might want to encourage their students to go back and explore.

Table 1. *Continued*

What happened?	My thinking
Teachers were able to revise their explanation. After this, I pointed out that *as new evidence became available you went back and revised your explanations. Scientists also do that. They sometimes modify or reconceptualize their explanations in light of new evidence.*	What at first seemed like a problem became an opportunity for me to introduce teachers to the tentativeness of science by pointing out a similarity between their own work and the work of scientists. In this sense I became more aware of how I could introduce ideas about the nature of science when teaching teachers. I realize that this was only possible because I was engaging them in activities that reflect the way scientists might go about their investigations. I also realized that if teachers want to emphasize aspects of the nature of science, it will be important for the activities they do with their students to reflect the norms of science.

This experience helped to challenge my assumptions about teachers as *learners* and my role as a teacher educator. I now better understand the difficulties teachers may encounter when learning about light and shadows, and I can use that to inform my future work. Experiencing discomfort brought forth the contradiction of viewing teachers both as experts *and* as novices, prompting me to rethink my role as a teacher educator and teachers' roles as learners. I now realize that I must be able to identify gaps in teachers' knowledge of science but also help them to identify these gaps themselves and find evidence to help them build new ideas.

PaP-eR 2: Seeing Things in a New Light (Eun's Story)

At the end of one learning cycle, I gave teachers a task intended to evaluate their understanding that light is necessary in order to see.

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

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

For nighttime in a city, I expected that teachers would draw some light sources and typical features of a city such as cars and buildings. For nighttime in a cave, I expected a blank paper. After I looked over the teachers' drawings I had two opposing feelings: satisfaction and concern. I was pleased with teachers' answers for *nighttime in a city*. They drew streetlights as light sources and drew buildings and cars that are typical features of a city. However, I was surprised with their drawings of nighttime in a cave, which included outlines or detailed pictures of a cave, spelunkers inside the cave, etc. Teachers seemed to have understood during their activities that they could not see anything when there is no light, so I was puzzled and decided to discuss this with our mentor. The following is part of our conversation:

Eun: *I am really disappointed with some of the teachers' drawings. I expected that all the teachers would answer correctly, but some of them did not.*

Mentor: *Does this necessarily mean that they don't understand? How would you categorize their "wrong" answers?*

Eun: *Many of them did not draw anything on this part. A few drew only outlines of inside of a cave. Others 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 also added light sources on the picture.*

Mentor: *It is important to understand why teachers gave those responses. In the evaluation phase, teachers' responses can be considered feedback on your instruction and can be valuable information for you to improve your instruction.*

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.*

Mentor: *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.*

Mentor: *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.*

Mentor: *It could be one reason. Could teachers have assumed that there is a light source or misinterpreted the direction as drawing a cave (as seen from outside) rather than drawing what they would see if they were IN a cave?*

Eun: *It could be that teachers do understand but interpreted the task differently. We'd better talk to these two groups of teachers to identify what was the problem to clarify the reason.*

Mentor: *Why do you think the fourth group of teachers who drew the 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: *Because they added a light source to their pictures, it suggests that they understood they need to have a light source to see the outside of a cave. However, it doesn't tell us whether they would have drawn nothing if there were no light source.*

Mentor: *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, we can better understand their thinking and identify any misunderstandings.*

I was taken aback when the assessment did not go as planned. I thought teachers would understand the task easily because they were *teachers*, not students. From a constructivist perspective, I understood that learners may interpret the same task in different ways. In hindsight, I see that my disappointment with the teachers' responses was not in line with my views of learning: I was unprepared for the differences in their responses and how to deal with them. My mentor encouraged me to consider the task from the teachers' perspective rather than my own. This helped me understand problems with the task itself and how these may have led to different interpretations. She also encouraged me to consider what teachers' responses revealed about their understanding, even if they were not the expected answer.

This incident helped me recognize inconsistency between my beliefs and practices. I responded to this situation as if getting the right answer were my goal; however, through discussion with my mentor I clarified that my purpose was actually to understand teachers' ideas. In reflecting with my mentor, I was able to reframe the experience to focus on teachers' ideas and their sources, not just the fact that teachers did not give a correct answer. I considered myself a teacher who valued students' understanding more than giving one correct answer, yet I had expected one correct answer from the teachers. I realized the impacts of my experiences as a student and a teacher back in Korea, where it seemed test scores were more important than actual understanding of students' ideas.

Analyzing teachers' responses was also useful in building my understanding. In my coursework, I had learned about different types of assessments tasks and their purposes. However, I did not have much experience actually making sense of learners' responses to various assessments and using those to guide my instruction. This encounter helped illustrate for myself the assessment cycle in action and how I could use assessment more effectively. In this sense, I strengthened my PCK, specifically my knowledge of assessment.

One of the things I want to help teachers do is to look beyond whether students' answers are right or wrong and to understand students' ideas. This experience enabled me to practice what I preach and to model this type of pedagogy. When we returned the assessment to the teachers, I was able to discuss this with them, showing them the four groups into which I had sorted responses and sharing how I had made sense of their ideas. Some confirmed my suspicion that they understood more than their drawing conveyed. They said our conversation highlighted how it would be similarly important for them to seek additional information from their own students about their thinking.

PaP-eR 3: Reflecting on a Teachable Moment (Deepika's Story)

When we designed the curriculum based on the 5E learning cycle, we chose activities we felt best fit in terms of the purpose to be achieved within each phase. For one of the 5E learning cycles, in order to introduce the law of reflection, we developed an activity we called *Target Tag*. For this activity, teachers worked in partners to try to hit targets placed in different positions around the room by positioning the mirror and the flashlight so that the light reflected off the mirror and onto the target. Although we expected this activity would help teachers recognize that the angle at which a beam of light reflects is equal to the incident angle, some pairs did not arrive at this conclusion. To us, it seemed the main difficulty was that they were not able to visualize the exact position of the mirror and the flashlight and could not translate what they were seeing into a model of the path of the ray of light. At that point I felt panic that the lesson was not working as we intended; how could we proceed to the next phase if teachers had not reached the conclusions we were anticipating after completing the activity?

I touched base with the other interns, who were experiencing the same thing. Suleyman commented that teachers did not seem to grasp that the purpose of the activity was not only to complete the challenge of hitting the target but also to understand the behavior of light in doing so. He noted some teachers got caught up in the excitement of hitting all the targets successfully and did not pay attention to how they aligned the mirror and the flashlight while doing so. We realized that it would not make sense to proceed to the next phase of the learning cycle and sought the help of our mentor.

Dr H. came up with the idea of another activity to help teachers visualize the path of the light ray. 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 follow the path of the ball, noting 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 experience provided us an alternative activity to use with small groups of teachers on our own. As we used this activity with teachers, it helped them visualize how different angles would be necessary for delivering the ball to the different catchers. Hence by visualizing the path of the ball (light ray) teachers were able to construct a rule for how light is reflected—the law of reflection. Intuitively, teachers knew where to aim the ball to make it get to the intended receiver. Retracing the path the ball traveled enabled them to visualize the angles at which it struck the wall and bounced.

I had learned about the importance of multiple representations in my education coursework; I knew that offering students opportunities to explore concepts hands-on, sharing visual representations of concepts, and engaging in discussions can all support learning. Yet in this instance I had difficulty putting that knowledge into practice. This experience also highlighted for me gaps in my own PCK for teaching about light: I did not have a good repertoire of representations on which to draw, but I was able to expand that repertoire. More importantly, I understand how this particular representation was stronger than our original activity—an insight that will be important for me when supporting teachers.

This makes me more cognizant of a challenge I will undoubtedly encounter as a teacher educator; although I have a background in physics, I may not have well-developed PCK for all disciplinary topics in the elementary curriculum, and this could limit my ability to support teachers in developing their PCK. I now see the value of collaboration and seeking help from others as a way to support the development of my own PCK for teaching science as well as for teaching teachers.

I also knew from working with my K–12 students that things do not always work out as planned, but when teaching teachers I realized I was holding myself to a higher standard. I understand now that teachers, just like students, will not always immediately grasp concepts from a single representation. I had overconfidently assumed that because teachers were adults and well, *teachers*, that they would have no difficulty with the concepts as

I was presenting to them. This was naïve; through this experience, I have come to see that teachers face the same difficulties and problems that *all learners* may encounter. Treating them as students would have been more helpful to me; I see now that I felt like a novice in this situation and was viewing them as experts.

Analysis of PCK Knowledge and Skills

Our Pa-PeRs, taken together, highlight key areas in which we needed to further develop our existing PCK for teaching science to *students* to effectively teach science to *teachers*. As Rebecca Cooper noted:

> As I began my transition from high school science teacher to science teacher educator, I started to recognize differences between my science teacher PCK and my developing science teacher educator PCK. I felt that while some aspects of my knowledge of teaching science were transferable into this new context, there were also other aspects that were significantly different for a science teacher educator. (Cooper et al., 2015, p. 65)

We too recognize elements of teaching science to students that apply when teaching science to teachers but also aspects of PCK for teaching science to teachers that we needed to develop. We describe three key areas of our development in the sections that follow: strengthening our personal PCK for teaching science; aligning our knowledge, beliefs, and practice; and understanding and viewing teachers as learners.

Strengthening Our Personal PCK for Teaching Science

The curriculum planning process equipped us with foundational knowledge from the profession, including topic-specific PCK. Yet during the internship there were times when we did not anticipate specific areas of difficulty or responses to assessments, or know alternative representations for a concept. These highlighted important ways we still needed to address gaps in our own *personal* PCK for teaching about light in order to effectively teach elementary teachers. Through the internship, we gained an understanding of how learners (in this case teachers) might approach a particular investigation (exploring factors that affect the size of a shadow), what specific assessments (drawing what you see in a cave) might reveal about learners' ideas, and the strengths and limitations of various representations of concepts (using bouncing balls to represent light rays).

Elementary teachers, who are generalists, will teach a broad array of topics in the elementary science curriculum. This means that elementary teacher educators will also require PCK for teaching a wide variety of science topics. As novice teacher educators, we were able to deepen our topic-specific PCK knowledge and skills for teaching light, expanding our repertoire of instructional strategies, activities, and representations in order to support elementary teachers in building their understanding. Yet we will most certainly find there are other science topics for which we need to strengthen our personal PCK as we continue our development as teacher educators.

Aligning our Knowledge, Beliefs, and Practices

Throughout the experience, we encountered gaps between our PCK and what we were able to do in our teaching (PCK and skills). We also confronted contradictions between our beliefs about teaching and learning and our practice. Key to forging this alignment was making our tacit knowledge explicit:

> The ability to articulate the purposes underpinning practice for oneself and others is a desirable professional competency to be developed by both teacher educators and student teachers. However, even though it may well be desirable, it is complex and difficult to do and is particularly difficult to develop alone. (Loughran & Berry, 2005, pp. 193–194)

Because we were collaborating with others who were also novices and shared our concerns and difficulties, we were encouraged to support one another and persist in the face of these challenges and contradictions. With the support of a more knowledgeable mentor whom we trusted, we analyzed critical questions to help resolve differences among our knowledge, beliefs, and practices. Additionally helpful was that our mentor was able to model this alignment as she shared the purposes underpinning her own teaching practice.

We recognize teacher educators have added pressure of modeling good pedagogy as they teach science to teachers. Our teaching methods signify to teachers how they might also teach their students. Indeed, for elementary teachers who did not have formal instruction about light prior to the professional development program, we were the only model they have for teaching this topic. Aligning our knowledge, beliefs, and practices when we teach science to teachers establishes important groundwork for supporting the development of their PCK. The importance of developing our PCK in this manner was underscored by our recognition and noticing of the ways in which teachers modeled their own behaviors in their small groups after the way we interacted with them as facilitators. Our internship did not extend beyond the content instruction sessions of the professional development program, which is a limitation we readily acknowledge. However, we find the self-study by Nyamupangedengu (2016) especially encouraging in demonstrating the possibility of supporting learning about teaching by modeling teaching practices.

Viewing Teachers as Learners

It is easy to assume that if teachers have weak content knowledge, that teaching science to teachers will be very similar to teaching science to students. Though we found the misconceptions teachers had and the ways in which they approached their investigations in some ways mirrored those of elementary learners, we also found ways in which teaching *teachers* was quite different from teaching *students*.

Perhaps most significantly, through a collective examination of critical incidents we recognized the inherent contradiction of viewing teachers *as learners*. We each viewed teachers as experts, which shaped our interactions with teachers, leading to feelings of hesitancy and uncertainty in our role as teacher educators. I (Eun) grew up in South Korea, where people have the utmost respect for the teaching profession and teachers. I was told "you should not even step on your teacher's shadow." In my (Deepika) home country of India, students also look upon their teachers with great respect and touch the feet of the teachers to seek their blessings. Students trust that all actions a teacher takes are directed toward their betterment, and students feel that it is their duty to obey the teacher without question. In Turkish culture, teachers are also viewed as the authority in classrooms. I (Suleyman) remember that as a K–12 student, I was often hesitant to ask my teachers questions because I did not want to be seen as questioning their authority. In Turkey, students are expected to listen their teachers carefully and follow their instructions. Given this, our discomfort and hesitance to "correct" teachers or point out their errors represents a tension we had to learn to navigate during the internship. As international doctoral students interning in a USA context, we realized important ways in which our culture influenced our practice and identities as teacher educators.

Viewing teachers *as learners* was a new experience for us, and our mentor helped us realize that *being learners* was also a different kind of experience for teachers. As we engaged in discussions of our teaching sessions, our mentor drew our attention to the different ways in which teachers responded to this role shift. Some of the teachers were open about their lack of content knowledge and expressed an eagerness to learn. Others had difficulty during sense-making activities as they focused on the idea they "knew" as opposed to the evidence before them. Still others failed to make this shift, positioning themselves as "experts" within their groups, and—while not intentional—interfering with the learning process of others. Our mentor modeled for us how to share the purpose underlying our teaching practices with teachers, making explicit the importance of skepticism and respect for evidence in science and science learning. We realize that understanding the importance of helping teachers make this role shift is unique to PCK for teaching *science* to teachers, as opposed to PCK for teaching teachers *about teaching*. By taking on the role of learner in lessons that model pedagogical strategies effectively, we believe teachers can more fully understand how these pedagogical strategies support the learning of their own students.

Conclusion and Implications

According to Cochran-Smith, there is a "need for more attention to what teachers of teachers themselves need to know, and to what institutional supports need to be in place in order to meet the complex demands of preparing teachers for the twenty-first century" (2003, p. 6). Through self-study, we sought to understand the PCK knowledge and skills necessary to transition from teaching science to *students* to teaching science to *teachers*.

While there are examples of doctoral internships and self-study in teaching science methods and practicum courses preservice teachers (Demirdogen et al., 2015; Wiebke & Park Rogers, 2014), our internship took place in the context of teaching science content to teachers in a professional development setting. We found this important for several reasons. First, developing content knowledge is a critical need for elementary teachers (Trygstad, Smith, Banilower, & Nelson, 2013), and therefore one that teacher educators should be equipped to address. Second, we were experiencing new modes of science instruction in our doctoral study that we had yet to put into practice ourselves. By participating in the planning, enactment, and analysis of instruction, we addressed important gaps in our PCK for teaching science, articulated and sought alignment between our beliefs and practices, and prepared ourselves to explicitly model the thoughts and actions underlying our own teaching (Loughran & Berry, 2005).

Throughout the internship experience, we encountered what might be easily dismissed as rookie mistakes—challenges that are in fact quite similar to those that beginning teachers face (Davis, Petish, & Smithey, 2006). The internship experience provided us with a safe space where we could make these mistakes and bump up against the limits of our PCK knowledge and skills in important ways. Through collaboration and self-study, our mistakes became rich opportunities for learning. As in the experiences of Vogel and Bartlett (2013), our work illustrates the value of self-study as a way to make doctoral teaching internships more meaningful. Engaging in self-study helped us build the capacity to study our own practice, which can in turn support our future professional learning and offer insights that lead to improvements in our practice (Nilsson, 2008).

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 our PCK as prospective teacher educators. Similar to Wiebke and Park Rogers (2014), our findings illustrate how having an experienced other or mentor during the process of self-study to discuss, reflect, and debrief the experiences is critical in terms of drawing useful insights relevant to developing one's PCK. For example, our mentor helped us shift roles as learners during content-focused instruction, critically examine our own role shifts as teacher educators, and articulate our underlying beliefs and assumptions.

Teaching (whether K–12 or higher education) can often be a solo experience, and this internship illustrated to us the value of discussions of our teaching with others. Engaging in what Calderhead and Shorrock (1997) termed *practice-focused discussions* (such as that illustrated in Pa-PeR 2) proved beneficial in helping us articulate our theoretical knowledge in ways that could inform our actions in particular situations. It was not just seeking one-on-one advice for how to handle a problem but also engaging with our peers and mentor to brainstorm together solutions that would be consistent with our beliefs about teaching and learning. This highlights the importance of continuing, as teacher educators, to seek out communities (whether at our own institutions or through professional organizations) so that we can continue to engage in practice-focused discussions.

While not the main focus of our inquiry, this work calls attention to the unique experiences of international doctoral students who are learning to become teacher educators within the USA. This is not something, to our knowledge, that has been a part of the growing discussion surrounding the preparation of future science teacher educators. Further inquiry surrounding the cultural differences between international doctoral students and the teachers they teach, as well as the differences between their experiences learning science in their own nations and that of students in the USA, may provide further insights into the role of culture in shaping prospective teacher educators' practices.

Acknowledgments – Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Disclosure statement – No potential conflict of interest was reported by the authors.

Funding – Originally funded by a grant from the Missouri Department of Higher Education, QuEST is now funded by a grant from the US National Science Foundation (grant number DRL-1316683), and this work was funded, in part, by that grant.

References

Abell, S. K. (1997). The professional development of science teacher educators: Is there a missing piece? *Electronic Journal of Science Education* [On-line], *1*(4). Retrieved from https://unr.edu/homepage/jcannon/ejse/abell.html

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30*, 1405–1416.

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

American Association for the Advancement of Science (1990). *Science for all Americans*. Washington, DC: Author.

Anderson, C. W., & Smith, E. L. (1986). *Children's conceptions of light and color: Understanding the role of unseen rays. Research Series No. 166*. East Lansing, MI: Michigan State University, Institute for Research on Teaching.

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

Berry, A., Friedrichsen, P., & Loughran, J. (Eds.). (2015). *Re-examining pedagogical content knowledge in science education*. London: Routledge.

Berry, A. K., & van Driel, J. H. (2012). Teaching about teaching science: Aims, strategies, and backgrounds of science teacher educators. *Journal of Teacher Education, 64*, 117–128.

Brown, A. L., Cocking, R. R., & Bransford, J. D. (2000). In Bransford, J. D., (Ed.), *How people learn* (pp. 285–348). Washington, DC: National Academy Press.

Bullock, S. M. (2009). Learning to think like a teacher educator: Making the substantive and syntactic structures of teaching explicit through self-study. *Teachers and Teaching, 15*, 291–304.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs Co: BSCS, 5*, 88–98.

Calderhead, J., & Shorrock, S. (1997). *Understanding teacher education*. London: Falmer Press.

Cochran-Smith, M. (2003). Learning and unlearning: The education of teacher educators. *Teaching and Teacher Education, 19*, 5–28. doi: 10.1016/S0742-051X(02)00091-4

Cochran-Smith, M., & Lytle, S. L. (1999). Chapter 8: Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education, 24*, 249–305.

Cooper, R., Loughran, J., & Berry, A. (2015). Science teachers' PCK: Understanding sophisticated practice. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 45–59). London: Routledge.

Daehler, K. R., & Shinohara, M. (2001). A complete circuit is a complete circle: Exploring the potential of case materials and methods to develop teachers' content knowledge and pedagogical content knowledge of science. *Research in Science Education, 31*, 267–288.

Daehler, K. R., Heller, J. I., & Wong, N. (2015). Supporting growth of pedagogical content knowledge in science. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 45–59). London: Routledge.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research, 76*, 607–651. doi: 10.3102/00346543076004607

Demirdogen, B., Aydin, S., & Tarkin, A. (2015). Looking at the mirror: A self-study of science teacher educators' PCK for teaching teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 11*, 189–205. doi: 10.12973/eurasia.2015.1315

Dinkelman, T. (2003). Self-study in teacher education: A means and ends tool for promoting reflective teaching. *Journal of Teacher Education, 54*, 6–18.

Duran, L., McArthur, J., & Hook, S. (2004). Undergraduate students' perceptions of an inquiry-based physics course. *Journal of Science Teacher Education, 15*, 155–171. doi: 10.1023/B:JSTE.0000044865.64149.62

Faikhamta, C., & Clarke, A. (2013). A self-study of a Thai teacher educator developing a better understanding of PCK for teaching about teaching science. *Research in Science Education, 43*, 955–979. doi: 10.1007/s11165-012-9300-7

Fulp, S. (2002). *The status of elementary science teaching: National survey of science and mathematics education*. Chapel Hill, NC: Horizon Research.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results from the PCK Summit. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 28–43). London: Routledge.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York, NY: Teachers College Press.

Hart, J., & Mars, M. M. (2009). Joint appointments and the professoriate: Two houses but no home? *Innovative Higher Education, 34*, 19–32.

Hume, A., & Berry, A. (2011). Constructing CoRes—A strategy for building PCK in pre-service science teacher education. *Research in Science Education, 41*, 341–355.

Lederman, N. G., & Abell, S. K. (2014). *Handbook of research on science education* (Vol. 2). New York, NY: Routledge.

Loughran, J. (2005). Researching teaching about teaching: Self-study of teacher education practices. *Studying Teacher Education, 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*, 12–20.

Loughran, J., & Berry, A. (2005). Modelling by teacher educators. *Teaching and Teacher Education, 21*, 193–203. doi: 10.1016/j.tate.2004.12.005

Loughran, J., & Northfield, J. (1998). A framework for the development of self-study practice. *Reconceptualizing teaching practice: Developing competence through self-study*, 7–18.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education, 31*, 289–307. doi: 10.1023/A:1013124409567

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.

McDermott, L. C. (1990). A perspective on teacher preparation in physics and other sciences: The need for special science courses for teachers. *American Journal of Physics, 58*, 734–742.

McDermott, L. C. (1995). *Physics by inquiry* (Vol. 2). New York, NY: Wiley.

McDermott, L. C., Shaffer, P. S., & Constantinou, C. P. (2000). Preparing teachers to teach physics and physical science by inquiry. *Physics Education, 35*(6), 411.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Nilsson, P. (2008). Capturing the complexity of practice: A self-study in the context of engineering education. *International Journal of Science Education, 30*, 1281–1299.

Nyamupangedengu, E. (2016). Using self-study to learn to teach genetics to pre-service teachers for understanding and for teaching. In G. A. Buck & V. L. Akerson (Eds.), *Enhancing professional knowledge of pre-service science teacher education by self-study research* (pp. 69–93). Springer International Publishing. doi: 10.1007/978-3-319-32447-0_4

Osmond, P., & Goodnough, K. (2011). Adopting just-in-time teaching in the context of an elementary science education methodology course. *Studying Teacher Education, 7*, 77–91.

Samaras, A. P., & Freese, A. R. (2006). *Self-study of teaching practices primer* (Vol. 12). New York, NY: Peter Lang.

Schon, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York, NY: Basic Books.

Shapiro, B. L. (1989). What children bring to light: Giving high status to learners' views and actions in science. *Science Education, 73*, 711–733. doi: 10.1002/sce.3730730610

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–23.

Shulman, L. S., & Hutchings, P. (2004). In S. M. Wilson (Ed.), *The wisdom of practice: Essays on teaching, learning, and learning to teach* (pp. 503–522). San Francisco, CA: Jossey-Bass.

Smith, D. C. (2000). Content and pedagogical content knowledge for elementary science teacher educators: Knowing our students. *Journal of Science Teacher Education, 11*, 27–46. doi: 10.1023/A:1009471630989

Smith, D. C., & Neale, D. C. (1989). The construction of subject matter knowledge in primary science teaching. *Teaching and Teacher Education, 5*(1), 1–20.

Tripp, D. (1993). *Critical incidents in teaching*. London: Routledge.

Trygstad, P. J., Smith, P. S., Banilower, E. R., & Nelson, M. M. (2013). *The status of elementary science education: Are we ready for the Next Generation Science Standards?* Chapel Hill, NC: Horizon Research.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673–695. doi: 10.1002/(SICI)1098-2736(199808)35:6<673::AID-TEA5>3.0.CO;2-J

Vogel, A. P., & Bartlett, A. (2013). Passing on a teacher educator's knowledge: Self-study of a doctoral teaching internship. *Studying Teacher Education, 9*, 130–140. doi: 10.1080/17425964.2013.808048

Wiebke, H., & Park Rogers, M. (2014). Transition to science teacher educator: Tensions experienced while learning to teach lesson sequencing. *Studying Teacher Education, 10*, 222–238. doi:10.1080/17425964.2014.949657

Wilson, S. M. (2006). Finding a canon and core: Meditations on the preparation of teacher educator-researchers. *Journal of Teacher Education, 57*, 315–325.

Wood, D., & Borg, T. (2010). The Rocky Road: The journey from classroom teacher to teacher educator. *Studying Teacher Education, 6*, 17–28. doi: 10.1080/17425961003668914

Zembal-Saul, C., Blumenfeld, P., & Krajcik, J. (2000). Influence of guided cycles of planning, teaching, and reflection on prospective elementary teachers' science content representations. *Journal of Research in Science Teaching, 37*, 318–339.