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Looking at the Mirror: A Self-Study of Science Teacher Educators' PCK for Teaching Teachers

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In this self-study, we aimed to delve into how re-designing and teaching re-designed practicum course offered to pre-service teachers (PTs) enriched our, as science teacher educators, development of pedagogical content knowledge (PCK) for teaching science teachers. This self-study was conducted during a compulsory practicum course in which we served as teaching assistants (TAs). The qualitative data collected through journal entries written by the help of mentoring experience, Content Representation (CoRe), reflection papers, formal observations of PTs' teaching practices and microteaching each week, formal and informal meetings with PTs. The results were presented through vignettes that included an emphasis on a critical examination of our prior practices, the changes made in the practicum, and the difficulties that PTs faced. This self-study was valuable for us regarding the development of our PCK and building interplay among all PCK components. In light of the experience we gained, implications for science teacher education and research were provided.

Keywords: PCK for teaching science teachers, science teacher educators, self-study, practicum

INTRODUCTION

> I am learning about science education, research, and teaching. But, how will I blend and enact these knowledge bases when I will start teaching pre-service teachers? (A doctoral student in science education, informal conversation)

The ability to prepare effective science teachers is directly related to the quality of teacher education programs (Darling-Hammond, Chung, & Frelow, 2002), which is determined by the quality of the courses offered by science teacher educators (STEs) (Aydın et al., 2013). Teaching assistants (TAs), who are both today's learners as doctoral students in science education and the STEs of the future, have a crucial impact on designing and teaching effective courses (Burgess & Mayes, 2007). Nevertheless, the kind of professional development TAs in science education receive has not been a major concern for doctoral programs (Abell, 1997). Therefore, TAs inevitably have major concerns about developing knowledge and practices for teaching future teachers, illustrated by the quote above. Why is this the case? To what extent do doctoral programs in science education provide effective support for TAs to tackle this challenge?

To answer these questions, first of all we must examine what kind of knowledge and support is offered by science education doctoral programs, and to what degree prospective STEs find those satisfactory. In a survey identifying the support provided by science education doctoral programs and the programs' expectations about prospective STEs (Jablon, 2002), it was revealed that programs mainly included two components: courses (e.g., nature of science [NOS] and

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State of the literature

- Doctoral programs do not necessarily support prospective science teacher educators' development for their future teaching practices.
- Science teacher educators are left alone during their first years of teaching teachers and have concerns about their ineffective preparation for teaching.
- Science teacher educator should have PCK for teaching science teacher for effective teacher education practices, which can be developed through taking various roles such as observer, apprentice, partner, independent instructor, and finally mentor during teaching of a course.

Contribution of this paper to the literature

- There is much to be learned about how science teacher educators learn how to teach science teachers and what opportunities are available for explicitly developing PCK for teaching teachers.
- How PCK for teaching teachers looks, and what definitions and examples exist in various teacher education contexts needs more clarification.
- Investigating the development of PCK for teaching teachers with different participants (e.g., TAs) and within different contexts (e.g., a practicum course) will enhance our understanding since studies in literature focused on science teacher educator's PCK in science teaching method context.

research methods and design), and research opportunities (e.g., independent study in science education). Although a course on science teacher education was missing in the programs, the same survey clearly pointed out that "100% of the doctoral program heads expected their graduates to be able to both teach science teaching methods course and supervise student teaching" (Jablon, 2002, p. 17). Moreover, prospective STEs explicitly stated that there was a large emphasis on research in their programs, which resulted in ineffective preparation for teaching (Fagen & Niebur, 2000; Nyquist & Woodford, 2000).

As evidenced by prospective STEs, science education doctoral programs are failing to include an important piece, namely, the explicit and purposeful consideration of how best to prepare prospective STEs (Abell, 1997; Abell, Park Rogers, Hanuscin, Lee, & Gagnon, 2009; Hanuscin et al., 2012). Abell (1997) also highlighted the ignorance of it: "Why is it that science educators have little to say about their own or their graduate students' professional development?" (p. 1). Abell (1997) was the first to put into words the missing piece of the puzzle. Abell stated that as a science teacher should have PCK, a STE should have PCK for teaching how to teach science teachers. Abell defined PCK for teaching teachers by the use of existing PCK ideas (i.e., Magnusson, Krajcik, & Borko, 1999). With the recognition of PCK for teaching teachers, STEs direct their research agenda toward defining their PCK and investigating how it developed as a result of various experiences (e.g., Abell et al., 2009; Faikhamta & Clarke, 2013; Hanuscin et al., 2012; Osmond & Goodnough, 2011). Within this recently growing body of literature, there is much to be learned about how STEs learn how to teach science teachers, what opportunities are available for explicitly developing PCK for teaching teachers (Abell et al., 2009), how PCK for teaching teachers looks, and what definitions and examples exist in various teacher education contexts (Faikhamta & Clarke, 2013). Therefore, the purpose of this self-study was to investigate how re-designing a practicum course and teaching that course contributed to the development of a group of TAs' PCK for teaching science teachers. In other words, this study was an opportunity to gaze into a mirror and consider what our collective experiences reflected, allowing us to offer useful information to other STEs.

THEORETICAL FRAMEWORK

Due to the fact that PCK serves as a road map for researchers (Friedrichsen, 2008), it has been seen as a valuable theoretical framework for examining both pre– and in-service teachers' practices in important aspects of teaching (i.e., instructional strategy, assessment, curriculum, and learner) (Nilsson & Loughran, 2012). Moreover, recent studies have successfully applied the PCK framework in understanding the knowledge and practice of STEs, as well as pre-service and in-service teachers (Abell et al., 2009; Faikhamta & Clarke, 2013; Osmond & Goodnough, 2011). Therefore, in order to examine the development of TAs' knowledge about teaching teachers during re-designing and teaching the re-designed practicum course, PCK was utilized as a framework.

Pedagogical Content Knowledge (PCK)

PCK is "the special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p.8). Since the coining of PCK by Shulman in 1986, several PCK models with different components have been proposed (e.g., Grossman, 1990; Veal & MaKinster, 1999; Magnusson et al., 1999). One of the most commonly cited PCK models was developed by Magnusson and others (1999). Magnusson and her colleagues suggested that PCK has five components, namely, orientation to science teaching, knowledge of instructional strategies, learner, curriculum, and assessment. In addition to being useful in defining the knowledge that effective science teachers should posses, PCK has been utilized to study the PCK of STEs for teaching pre-service teachers (PTs). In addition to science teachers, "[s]cience teacher educators are expected to use this PCK as a guide to plan learning activities and teaching practices in developing science teachers' PCK" (Faikhamta & Clarke, 2013, p.960).

The idea of PCK for teaching teachers was initially put forth by Abell (1997). Using the existent PCK model proposed by Magnusson et al. (1999), Abell and her colleagues developed a PCK model for teaching science teachers (Abell et al., 2009). The modified model includes five components that are parallel to the components of the original model. However, the new ones describe teaching a science teaching methods course. Although the model is designed for the methods course, it can be easily adapted for any course (e.g., field experience) or professional development program (Abell, Appleton, & Hanuscin, 2010). The basic components of PCK for teaching teachers are orientation to teaching teachers, knowledge of science teachers (i.e., as learners of science and its teaching), knowledge of curriculum for teacher education courses, knowledge of instructional strategies for teaching courses in teacher education program, and knowledge of assessment for science teachers' learning in those courses. All the fundamental components of PCK for teaching science teachers include sub-components. To inform the readers about the components and sub-components of PCK for teaching teachers, the PCK model that framed this study was elaborated in Table 1 with its basic components, sub-components, and explanations.

Orientation to teaching teachers forms a lens through which teacher educators view both teaching science teachers and science teaching. For instance, it may be activity-driven orientation through which STEs focus on including activities in the method course to help PTs develop a collection of science activities. Or, it may be a topics orientation that directs STEs' practice toward a more specific piece (e.g., inquiry-based teaching, technology integration) (Abell et al., 2010). Second, STEs should also be knowledgeable about PTs difficulties (e.g., PTs may have difficulties in implementing inquiry strategy for teaching genetics topic), prior knowledge about teaching and science, and misconception about science (e.g., PTs may think that 'scientists are totally objective in their work', which is a misconception about NOS) and science teaching, their attitudes towards science teaching, and PCK with its all sub-components (e.g., orientation to science teaching and knowledge of learner). Third, curriculum knowledge includes determination of the aims and purposes which will guide teacher educators' actions and decisions in the method course as well as knowledge about the resources suggested to PTs and utilized in the course. STEs should know the importance of the course in the teacher education program. For example, if it is practicum course, then the main goal can be to make PTs perform teaching practice and make them implement what they have learned in the previous courses. Additionally, STEs should determine the aims for teaching the course and form the syllabus for the course. Fourth, knowledge of instructional strategy includes being well informed both about the subject-specific strategies (e.g., implementing conceptual change to address misconceptions) and topic-specific strategies representations (e.g., use of animation to teach abstract topics) for teaching science and those for teaching science method course (e.g., in the science teaching method course STE should teach predict-observe-explain to PTs). Finally, STEs should decide what to assess (e.g., assessment of PTs' PCK development, PTs' instructional strategy implementation, and PTs' NOS understanding) and how to assess (e.g., through the use portfolio, observation notes taken while PTs are performing microteaching episodes) in the method course. Although the model is designed for the method course, it can be easily adapted for any other course for training PTs.

Recently, STEs have paid explicit attention to examining their own PCK, especially in science teaching method courses (e.g., Abell et al., 2009; Faikhamta & Clarke, 2013; Osmond & Goodnough, 2011) through self-study methodology. In the next section, the literature review will include the context of the studies conducted, important results revealed, and points to be discussed.

LITERATURE REVIEW

Self-study is a kind of practitioner research that Hamilton and Pinnegar (1998) have defined as "the study of one's self, one's action, one's ideas" (p.236). In the context of teacher education, self-study can be described as "systematic research and reflection by teacher educators on their own practice" (Lunenberg et al., 2007, p.414). Dinkelman (2003) stated that self-studies conducted in the teacher education field produce knowledge not only for the participating teacher educators but also for other teacher educators who will read the self-study.

In science teacher education literature, there have been ongoing debates about which strategies are best suited to develop STEs' PCK for teaching teachers (Abell, 1997). Self-study is one of the methods that researchers have used to explore what supports are necessary for the development of PCK for teaching

Table 1. PCK for Teaching Science Teachers Model Modified From Abell et al. (2010)

PCK components	Sub-components	Explanation
Orientation to teaching science teachers	Beliefs about learning how to teach	STEs' thinking about the way science teachers learn about science teaching
	Beliefs about teaching how to teach	STEs' goals and purposes for the teacher education course (e.g., activity-driven science teaching method course to help PTs develop a collection of science activities)
Knowledge of science teachers (as learners of science and its teaching)	Knowledge of science teachers' learning about science and NOS	STEs' understanding of science teachers' requirements for learning science and NOS as well as their difficulties and misconceptions about science and NOS
	Knowledge of science teachers' learning about science teaching	STEs' understanding of science teachers' requirements for learning science teaching as well as their difficulties and misconceptions. It includes science teachers' attitudes toward science teaching and their PCK for teaching science (e.g., orientations and knowledge of instructional strategy)
Knowledge of curriculum for teacher education courses	Knowledge of the science teacher education program	STEs' understanding of goals and purposes of the courses in a teacher education program, what they learned in previous years and what they are expected to learn in the following years
	Knowledge of aims, goals, and content of teacher education courses	STEs' understanding of what to include in a course (e.g., integrating PCK in a practicum course), and goals and purposes for teaching that course
Knowledge of instructional strategies for teaching courses in teacher education programs	Knowledge of subject-specific strategies for science and its teaching	STEs' understanding of teaching strategies used for teaching science (e.g., inquiry) and teaching science teachers (e.g., predict-observe-explain)
	Knowledge of topic-specific strategies for science and its teaching	STEs' understanding of strategies for teaching particular topics in science (e.g., analogies) and science teaching (e.g., explicit use of PCK through Content Representation [CoRes] for enhancing science teachers' PCK)
Knowledge of assessment for science teachers' learning	Knowledge of dimensions of science teachers' learning (What to assess)	STEs' understanding of dimensions of science teachers' learning to be assessed (e.g., science content, pedagogy, PCK, and attitudes)
	Knowledge of methods of assessing science teachers' learning (How to assess)	STEs' understanding of methods of assessment of science teachers' learning in a teacher education course (e.g., test including multiple-choice items, reflection papers, and CoRes)
	Knowledge of purpose of assessing science teachers' learning (Why to assess)	STEs' understanding of purpose of assessment of science teachers' learning in a teacher education course (e.g., to follow PTs' development [formative] and to grade [summative])

teachers and to consider what a STE needs in order to support PTs' PCK development. Regarding this point, Abell and her colleagues (2009) proposed a model for developing PCK for teaching teachers through investigating their own experiences as doctoral students and faculty members. In light of their experiences, they stated that doctoral programs should include experiences such as observing a science teaching method course and implementing it with a veteran teacher educator or independently.

Similar to Abell et al. (2009), other STEs have, through self-studies, investigated the effect of different experiences on the development of PCK for teaching teachers. Hanuscin et al. (2011) investigated the development of their PCK throughout mentored internship experiences. Three graduate students (mentees) and an STE (mentor) worked collaboratively during a 2-week summer institute intended to provide professional development for K-6 teachers. Mentees implemented the 5E learning cycle instructional strategy for teaching the topic of light. During the implementation, mentees resolved problems by communicating with their mentor. It was seen that the mentored internship experience helped mentees to bridge the gap between their pedagogical knowledge and practice. In another study, Hanuscin et al. (2012) explored the effect of a course on designing and teaching science teaching method course on the development of doctoral students' PCK for teaching teachers. The course included seminars given by outstanding STEs via Skype, field experience, designing a course syllabus, and the development of a research concept paper. As a result of the study, doctoral students deepened their knowledge of learner and curriculum, broadened their repertoire of instructional strategies, and developed their knowledge of assessment in the science teaching method course. In addition, designing a course syllabus provided an opportunity for doctoral students to bring all PCK components together and fostered the integration of those components.

Additionally, some STEs investigated their own PCK when teaching a science teaching method course. In a study by Faikhamta and Clarke (2013), Faikhamta studied himself as a beginning STE, and investigated his beliefs and teaching practices using the PCK framework in the context of a field-based science teaching methods course. Through this self-study, he realized that, although he held strong PCK for teaching science, his PCK for teaching science teachers was limited, especially in terms of knowledge of instructional strategies and knowledge of assessment of science teachers' learning. Similarly, Osmond and Goodnough (2011) investigated the development of a novice STE's PCK in the context of an elementary science education method course that included Just-in-Time Teaching (JiTT), a teaching and learning strategy involving interaction between web-based study assignments and face-to-face class sessions. During the course, PTs were asked to respond to three online assignments in order to probe their understanding of science concepts. Pulling from the PTs' online responses, the STE designed her teaching and learning activities. Through this self-study, the STE mostly enhanced her knowledge of learner. With the help of PTs' online responses, she was able to identify PTs' prior understandings and common misconceptions.

Although there has recently been an increase in the number of studies on PCK for teaching teachers, further research is needed to understand the process through which STEs develop PCK and which opportunities/contexts are especially helpful (Abell, 2009; Faikhamta & Clarke, 2013; Hanuscin et al., 2012). Investigating the development of PCK for teaching teachers through self-study with different participants (e.g., TAs, beginning STEs, and experienced STEs) and within different contexts (e.g., a practicum course) will enhance our understanding. In addition, examining the effect of different experiences (e.g., providing mentoring to PTs) on STEs' PCK for teaching teachers will make significant contributions to the field of teacher education. Therefore, the research question guiding this self-study was as follows: How did re-designing and teaching a re-designed practicum course contribute to the development of STEs' PCK for teaching teachers?

METHODOLOGY

Self-study

In this study, we utilized self-study as a methodology to explore how re-designing and implementing a practicum course contributed to our development of PCK for teaching teachers. Self-study is an effective approach for reflecting on STEs' own PCK development (Loughran, 2007), for improving the quality of teacher education programs, and for developing professional knowledge based upon teaching and learning (Garbett, 2011).

There is no single way to conduct self-study, but it is important to carry out the study in a systematic manner—collecting data from multiple sources, analyzing them methodically, and reporting on them in a way that others can learn from (Ezer, 2009). LaBoskey (2004) identified four methodological features of self-study: self-initiated and self-focused, interactive or collaborative nature (i.e., sharing beliefs, experiences, and practices with colleagues), improvement-aimed (i.e., requirement of evidence of reframing and transformation of practice), and gathering data from multiple sources (i.e., primarily qualitative) (cited in

Berry, 2007). In the next section, our self-study is described considering these characteristics.

Background of the Researchers

We, formerly three experienced TAs and currently independent instructors (Aida, Brenda, and Sandi[1]), graduated from a 5-year secondary science teacher education program that provides courses on content (e.g., organic chemistry), pedagogy (e.g., development and learning), and subject-specific pedagogy (e.g., science teaching method course). After graduation, we started our academic career as both a doctoral student and a TA in the same department in 2005. We have assisted and co-taught science teaching method and practicum courses since 2006. Additionally, in the first two years of the PhD, we were so intensively interested in teacher education that we decided to study science teacher education for our doctoral dissertations and research. Moreover, with a government scholarship, two of us, Brenda and Sandi, spent a year in the US developing teaching and research skills, especially in teacher education. We also took doctoral courses on PCK and science teacher education, and conducted research with our colleagues in the US. After the visit to the US, we re-started teaching the science teaching method and practicum courses in Turkey. As a result, from the beginning of our academic career, we had opportunities to communicate PTs, to get information about their difficulties and misconceptions about chemistry content, to observe their teaching practices, and to recognize their difficulties and deficiencies in teaching chemistry while serving as TAs during the undergraduate courses. Moreover, doctoral courses on teaching and learning, previous research studies on teacher education enable us to be knowledgeable about teacher education. Additionally, we attended a special science education doctoral program where we became faculty in a college of education in a different university right after our graduation. Therefore, in this study, we preferred to refer to ourselves both as TAs and STEs. We used those terms interchangeably throughout the study since we have been essentially STEs who were formerly TAs and currently independent instructors.

Context of the self-study

This self-study was conducted during a five-credit, compulsory practicum course offered to senior PTs. Before taking the practicum, PTs have to take chemistry content courses (e.g., analytical chemistry), pedagogy courses (e.g., development and learning), and science-specific pedagogy courses (e.g., science teaching method course I and II). In the practicum, PTs have a chance to enact what they have learned in all courses taken previously. Two types of teaching experiences are offered to PTs in the practicum: (1) weekly microteaching sessions held in the college of education and (2) teaching practices in the partnership high schools. First, for the microteaching sessions, PTs are supposed to plan and enact 30-minute long microteachings on a prescribed topic (e.g., acid strength). Each week two PTs perform microteaching and others observe them. Then, group discussion is held on the strengths and weaknesses of the microteaching enacted. Throughout the 14-week semester, each PT has at least 3-4 chances to plan and perform microteachings in front of peers, TAs, and the instructor of the practicum. Second, PTs are assigned to a partnership high school and are supposed to spend one day in the high school each week during the semester. Their responsibilities are observing veteran teachers, focusing on learners' difficulties and misconceptions, planning and enacting teaching in the classroom context, and assisting teachers (e.g., helping them prepare laboratory activities).

As STEs, serving as TAs during the time of the study, we realized that there are some missing pieces in the practicum after teaching it for four years. For instance, although PTs took science teaching method courses, they were still not able to apply teaching methods. Even if they enacted a particular method (e.g., learning cycle), they implemented it merely for the sake of implementing it. For example, there was no consistency between the instruction and assessment strategies utilized by PTs. Furthermore, we recognized that PTs were not able to orchestrate what they had learned in previous courses (e.g., assessment in science education and science curriculum development and instruction). Worse, three PTs failed the practicum course in the spring semester, which triggered the necessary reforms in the practicum for the following semesters. In light of our disappointing previous experiences in the practicum course and recent PCK research literature, we realized that it was time to revolutionize the practicum course, so we recommended that the instructor of the practicum re-design the course.

Former TAs and currently independent instructors, the authors of this study, focused on what to exclude and include in the practicum. The reform attempts can be categorized into four main groups. The first was offering mentoring support to PTs from experienced TAs before enacting microteachings and teachings in partnership high schools. Because mentors in partnership high schools commonly teach in a traditional, teacher-centered way (Nakiboglu, Karakoc, & De Jong, 2010), we thought that it would be better if mentoring support was provided by TAs instead of teachers. Mentoring is valuable due to its role in

[1] All names are pseudonyms

teaching novice teachers and PTs how to teach in a reform-based way (Bradbury, 2010; Feiman-Nemser, 1998). In 2001, Feiman-Nemser criticized the classic mentoring framework and suggested educative mentoring for "cultivating a disposition of inquiry, focusing attention on student thinking and understanding, and fostering disciplined talk about problems of practice" (2001, p.28). In this study, we adopted educative mentoring and provided long-term support to PTs. In the mentoring meetings held before microteachings and teachings in the partnership-high school, PTs and TAs came together and discussed the pre-plan prepared by PTs. Additionally, suggestions for useful sources (e.g., activity books) and resources (NSTA web-site, etc.) related to science teaching and assessment were offered. Furthermore, TAs asked guiding questions about planning the instruction in order to make PTs think about how to teach, focus on learners' prior knowledge, and assess learners' understanding. No directive suggestions were provided to PTs—on the contrary, we paid special attention to having a guide role rather than that of a director. To reach consensus on how to meet the requirements of educative mentoring, TAs, who served as mentors, and the instructor of the course met and discussed at the beginning of the practicum. Also, we were all present in the first educative mentoring session of a PT. We reflected on the educative mentoring session afterwards to ensure consistency in the following educative mentoring sessions where each mentor will be alone with the PT. The instructor of the course only participated to the first three meetings; deciding how to conduct educative mentoring, first educative mentoring session, and reflection on the session to negotiate. Only TAs provided educative mentoring to PTs throughout the practicum course.

As a second effort, we drew on PCK as a base for the practicum course, including an explicit PCK introduction with topic-specific examples at the beginning of the semester. We prepared a presentation about PCK to introduce this construct to PTs. During the presentation, we explained what each PCK component means with examples from chemistry (e.g., knowledge of learner: "Learners may think that the anode is always on the left side in an electrochemical cell") and then requested that PTs give different examples. Third, we excluded existing assignments (e.g., reports related to general pedagogical issues) and included papers through which PTs are supposed to reflect on their own PCK development through the practicum course, the sources of the PCK development, and veteran teachers' PCK in the high schools. Finally, we excluded lesson plans and included Content Representation (CoRe), which was developed by Loughran, Mulhall, and Berry (2004), as a tool for both lesson preparation and capturing PTs' PCK. Before integration of CoRe (i.e., before the self-study), PTs used to plan their lessons using "lesson preparation method". Within this method, PTs were asked to state and explain their objectives, instructional materials, teaching strategy, and assessment methods step by step. The instructor of the practicum agreed to the changes suggested, and we enacted the reformed practicum course.

All modifications made were informed by both our experience in the practicum and science teacher education literature. The modified version of the practicum was entitled "Mentoring enriched PCK-based practicum course" and offered in two semesters. At the end of the first semester, some more modifications were carried out, which is an indication of the improvement-aimed features of self-study. During the modification period, as TAs we had more chances to study with PTs, and to notice their weaknesses and needs. Therefore, in this study, we shared our practice, reflection, and PCK development for teaching teachers, which reflects the self-initiated characteristic of self-study.

Data Sources and Analysis

The qualitative data collected through journal entries written by the help of mentoring experience, CoRe, reflection papers, formal observations of PTs' teaching practices and microteaching each week, formal and informal meetings with PTs. The data were collected throughout two semesters. Data collection tools and process were the same for both semesters. Therefore, data collection process for one semester is represented in Figure 1. Meetings with PTs on their planning and their teaching practices, their CoRes, and observing their teaching practices, provided information about PTs' knowledge about how to teach science, i.e., their PCK. All the meetings with PTs were recorded and transcribed in verbatim. Additionally, such information getting through the practicum indicated the effectiveness of the mentoring enriched PCK-based practicum course on their PCK development. Thus, we had an opportunity to develop our knowledge about how to teach teachers.

The journal entries were analyzed in three steps. First, each author coded her journal entries independently. We paid attention to every single incident, discussion with PTs, and observations in the practicum. The components and sub-components of PCK model proposed by Magnusson et al. (1999) and Abell et al. (2009) enlightened the data coding and analysis. After coding the whole data, in the second phase, we, independently, put the codes under the categories that are the components (e.g., knowledge of learner) suggested in the PCK model (Table 2). In other words, deductive analysis based on existing codes and categories was applied (Patton, 2002). In the third part,

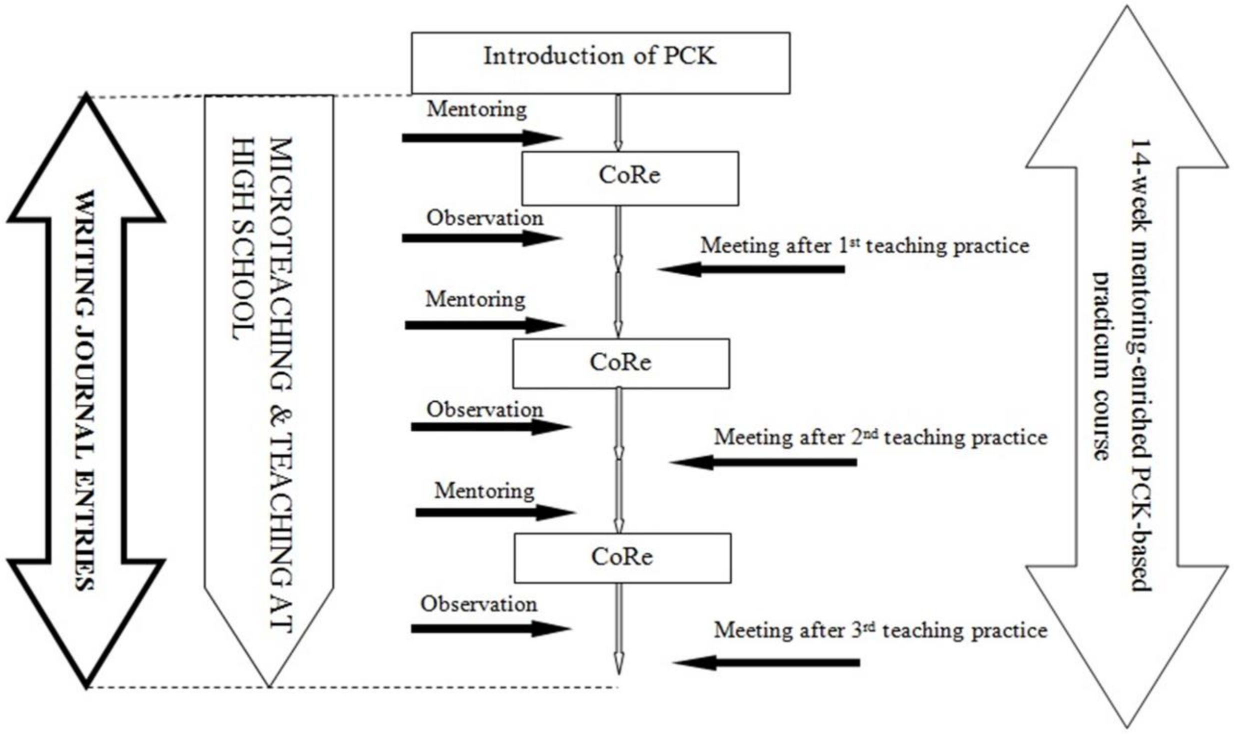

Figure 1. Data collection process through the semesters

Table 2. An Example of Data Coding, Codes, and Categories

Incidents	Codes	Category	Description of the category
Assessment is the most problematic part for PTs in planning and enacting teaching. I was aware of the problem from the very beginning. Additionally, although I observed more or less development in other parts (e.g., use of instructional strategy), we have had stacked into the assessment. When we talk about the problem, one of the PTs posited:	PTs' difficulty in assessment	Knowledge of learner (knowledge of PTs' difficulties)	It includes teacher educators knowledge about PTs' difficulties, prior knowledge, and misconceptions about science (*e.g., scientific knowledge is absolute*) and science teaching (*e.g., implementing instructional and/or assessment strategies*)
I: Do you think you are adequate in the implementation of different assessment techniques to assess learners' understanding?			
PT-1: No, not really.			
I: Why not?			
PT-1: Because the only thing provided us…I mean, when you say assessment, the only thing that comes to my mind is test including open-ended, multiple-choice, and/or true-false… Those come to my mind but I am not able to think about others now. So, this is not enough in my opinion.	PTs' inadequacy in the repertoire of assessment techniques	Knowledge of learner (knowledge of what prior knowledge that PTs have had)	

to ensure credibility, data and investigator triangulations, peer-debriefing, member checks, and long-term observation were employed (Patton, 2002).

After completing coding and categorization of the data, for each PCK component, we provided a vignette that included an emphasis on a critical examination of our prior practices, the changes made in the practicum, and the difficulties that PTs faced. A vignette is "an evaluation and discussion tool for monitoring and developing teachers" (Veal, 2002, Vignettes, para. 1). In this study, vignettes were used to share our experience as teacher educators in the practicum course with other teacher educators. Moreover, in the practicum course we utilized content-specific vignettes (Veal, 2002) to assess PTs' PCK, which is explained in the vignette written for knowledge of assessment component in the results. After each of us wrote vignettes for each PCK component, we conducted a cross-case analysis for checking how we, three STEs (i.e., former TAs, and currently independent instructors), had different types of improvement through the experience we had in the practicum course over a year. Cross-case analysis showed us a great similarity regarding the most and least developed PCK components that each STE reflect on, the experiences that each STE had during mentoring meetings and the difficulties that each of us faced with. Likewise, we realized that we had a very similar development in our PCK for teaching teachers and parallel experiences. Finally, we held meetings to select the most interesting, eye-opening vignettes with rich examples of PCK for teaching educators. Thus, we addressed both gathering data from multiple data sources and the collaborative nature of self-study.

RESULTS

In order to describe the whole picture of our development in PCK for teaching teachers, we provided a set of vignettes based on our experiences during the designing and teaching of the re-designed practicum course. The vignettes answered specific set of questions which are: What was the nature of our PCK components before teaching practicum course? How did the practicum course contributed to enhancement of our PCK? How did nature of our PCK components change? and What kind of changes did we reflect to our practice as a result of change in our PCK components? We framed our experiences around the PCK model formed by Magnusson et al. (1999) and the PCK for teaching teachers model offered by Abell et al. (2009). For each PCK component, we presented the most informative vignette, as mentioned in the data sources section. However, for orientation of components, we offered a joint experience of three STEs.

Orientation to Teaching Teachers: Beliefs about learning how to teach and teaching how to teach (A Joint Story)

In the first several years of our academic career, we thought that the more PTs knew about different instructional strategies (e.g., conceptual change and inquiry), the more effective they were going to be when teaching their subject. That orientation was pedagogy-driven. Therefore, in the science teaching method and practicum courses, we always encouraged PTs to use a particular instructional strategy in their microteachings and in the teachings in their field experiences. At that time, we were not concerned much about whether PTs considered students' misconceptions and difficulties in their instruction, if their instructional strategy aligned with their objectives and included topic-specific strategies, or if their assessment was formative as well as summative. However, we realized that there were some problems in the PTs' teaching. For instance, they stated possible misconceptions that learners might have in the lesson plan but did nothing to address them throughout the instruction. Or, they just planned to do a series of activities since they were expected to do so, and prepared an assessment task that was not relevant to the objectives they wanted to achieve. Therefore, we initiated the critiques by examining our goals in the course. We asked ourselves: "What are the goals and purposes we aimed for?" Group discussions enriched by teacher education literature—specifically PCK—and unsatisfactory experiences lent a hand for the shift in our orientation. Our new goal was to design a practicum through which meaningful opportunities were provided to PTs to make them chemistry teachers who are capable of teaching for understanding rather than memorization. Moreover, we seek to create an environment that promotes teaching assistant–pre-service teacher relationships and mutual learning. In other words, our ideal is a win-win situation that enriches both STEs' PCK for teaching teachers (e.g., learning about the difficulties that PTs confront) and PTs' PCK for teaching chemistry (e.g., how to use curriculum). Additionally, the tacit nature of teachers' professional knowledge and PTs' lack of a teacher perspective helped us to expand our orientation to include reflection orientation. PTs were more able to confront and change their ideas on science teaching through engaging in reflection in various contexts such as reflection on others' teaching and reflecting on their own teaching. Hence, our innovative orientation is PCK- and reflection-driven. To sum up, both the PTs enrolled in the practicum and we as TAs focused on PCK as a professional knowledge base for teaching and reflect on our performance. As you will notice in the following sections, we put PCK and reflection in the heart of the practicum.

Knowledge of Learners: Brenda's Vignette

The knowledge of learner component of PCK for teaching teachers was elaborated under its sub-components, namely, knowledge of science teachers' learning about science and NOS and knowledge on PTs' attitudes toward science teaching. Knowledge of science teachers' learning about science and NOS component refers to what STEs know about teachers' subject matter knowledge (SMK). Teachers' SMK includes their knowledge about the science (e.g., physics and chemistry) and NOS (i.e., teachers' knowledge about science, scientific knowledge, and scientific practice) (Magnusson et al., 1999). Therefore, a STE who has a robust knowledge on this subcomponent of PCK for teaching teachers should be knowledgeable about (a) what science teachers know about science concepts, (b) what science teachers know about NOS, (c) what skills and knowledge science teachers require to meaningfully learn science content and NOS, and (d) what difficulties and misconceptions that science teachers have about science and NOS.

Knowledge of science teachers' learning about science and NOS

This is the least developed component of my PCK for teaching teachers since I have been a TA of various courses (e.g., practicum course and method course) and doing research on teacher knowledge for seven years. I knew that most of the PTs were having difficulty in understanding several chemistry topics (e.g., electrochemistry and solubility) and NOS (e.g., the difference between theory and law) and had misconceptions about those as well. To address these difficulties and misconceptions, I was lecturing about them after the PTs had performed their microteachings in several courses (e.g., science teaching method). However, my experiences in designing and especially in teaching the practicum course alerted me that the retention of PTs' meaningful understanding was low (i.e., although they learn about NOS in the science teaching method class, they have difficulty in conducting an effective explicit-reflective discussion on several NOS aspects). Moreover, I realized that PTs have difficulty in understanding how a chemistry topic (e.g., liquids) is related to other topics in chemistry and to other disciplines (e.g., physics).

PTs' difficulties and misconceptions about chemistry topics and NOS were resistant to change, even after they were addressed in several courses (e.g., lab experiments in science education). Furthermore, my knowledge of PTs as learners of science increased in terms of more specific difficulties and misconceptions that PTs had about chemistry and NOS. For instance, one of the PTs asked me to explain the changes in particles' potential and kinetic energy before, during, and after the formation of an activation complex. She had difficulty realizing how potential and kinetic energy changes at different times during the reaction. Another example is that all PTs enrolled in the practicum had difficulty in differentiating between instantaneous and average rate. In terms of NOS, during one of the PTs' microteachings, I, as a TA, suggested to him that he could have taught the difference between science and technology. Thereupon he and the other PTs asked me what the difference between them was. Although PTs know about several NOS aspects (e.g., tentativeness of scientific knowledge), they were having difficulty in giving examples. Moreover, they were not able to define what science is.

My experiences with a PCK-orientation throughout the course informed me that PTs' aforementioned difficulties and misconceptions may impede the successful translation of their science content and NOS knowledge into a form that is understandable for students. Therefore, in the practicum I always directed PTs to revisit their chemistry and NOS understanding before their microteachings and used Socratic dialog, especially during mentoring. For instance, I asked them "What should a student who meaningfully understands … concept know and be able to do? Which chemistry, biology, physics, etc. concepts should students know for understanding ….? Which NOS aspect can you integrate into your teaching and how can you do it?" Those questions helped PTs to realize their own difficulties and misconceptions, and facilitated the transformation of their subject matter knowledge into a form that is understandable for students.

PTs' Attitudes towards Science Teaching

Owing to my experiences as one of the TAs of the practicum course, I realized that some PTs had negative attitudes as well as lower motivation towards teaching chemistry than others. This was evidenced by the insufficient effort they put for their microteachings and teachings. When I searched for the reasons, PTs stated that they were concerned about being hired as a chemistry teacher in private or public high schools due to the high number of teachers graduating from the department every year. Another reason was that some PTs were seeking an academic career in chemistry and already studying with chemistry professors. So, they did not want to pursue a career in chemistry teaching. Before the practicum course, I was aware of PTs' negative attitudes towards chemistry teaching. However, the PCK orientation notified me about the importance of PTs' belief in their PCK development since PCK is an amalgam of knowledge and beliefs (Magnusson et al., 1999). The reflection of this realization in my practice was in my consideration of PTs' differences as learners of science teaching and in preparing them for different careers (e.g., being a chemistry teacher and being a chemist). Throughout the practicum course, I always asked their future career plans. For those not pursuing a career in chemistry teaching, I especially emphasized the importance of PCK since they may need to transform their chemistry and NOS knowledge into a form that is understandable by others. For instance, I explained to one of the PTs pursuing an academic career on pure chemistry that she would need to develop PCK for teaching chemistry to learners who have different majors, which necessitates knowledge of learner and instructional strategies. These experiences also encouraged me in using more formal qualitative and quantitative methods to determine and analyze PTs' beliefs and attitudes. That is, my knowledge of learner informed both my knowledge of assessment and of instructional strategy.

Knowledge of Curriculum: Aida's Vignette

Knowledge of the science teacher education program.

Before the self-study practice, we just focused on the program catalog, thinking that since PTs took Science Teaching Methods I and II, Assessment in Science Education, and Science Curriculum Development and Instruction, they should be able to bring them into play when planning and enacting their plan, which was not the case. I was originally just criticizing PTs and complaining about the situation. However, after study with PTs throughout a year, I learned that some of these courses are not effective in preparing PTs for the teaching profession. During the mentoring, I had a chance to talk with PTs and get information about the efficiency of courses in the teacher education program. I asked several questions to learn more about the teacher education program curriculum: "Have you ever reviewed the chemistry curriculum in the courses you take? What did you learn about assessment in your assessment course? When did you take these courses?" The results of such communication with PTs helped me to diagnose the problem: a lack of or inadequate use of subject-specific and topic-specific examples of how to assess and how to focus on curriculum goals. Additionally, my experience with PTs helped me realize that PTs' lack of teaching experience made it worse. Luckily, with recognition of the problem, we included an explicit introduction of how to use curriculum materials and a topic-specific PCK workshop (electrochemistry, which was selected by PTs enrolled in the practicum), which catalyzed their understanding of curriculum and how to implement it.

Knowledge of aims, goals, and content of teacher education courses.

In addition to my development of knowledge of curriculum of the teacher education program, I also had a better set of goals and purposes for the practicum course. Previously, we, as a group of TAs and the instructor, aimed to develop PTs' teaching by providing teaching experiences (e.g., microteachings held in college of education and teaching in partnership high schools). We had thought that teaching practice would help PTs be better teachers. With the help of experiences before and after the self-study, we realized that only practicing is not helpful. We saw those problems; PTs' lesson plans and accompanying instructions were fragmented and far away from ensuring students' learning of the topic meaningfully. Also, they were using an instructional strategy (e.g., 5E) for the sake of using it and without necessarily satisfying the conditions of that instructional strategy (i.e., no link between explore and engage phase of 5E). Their assessments were also inefficient since what and how they assess did not match with what they teach. For instance, before the self-study one PT stated that she used drama to teach effective collisions in rate of reaction topic since it's enjoyable for students. In light of teacher education literature and our research, we found that not only having teaching experience but also being knowledgeable about teaching, especially having PCK, is important. Therefore, we intended to provide more meaningful opportunities to train PTs as practitioners who are able to teach chemistry for understanding, and to focus on learners' needs. Moreover, we aimed for the PTs we educated to be aware of contemporary teaching and assessment strategies, and knowledgeable about PCK.

Due to the realization that providing occasions to teach does not guarantee training, we decided to re-design the practicum course. Additionally, our reforms were not a one-shot; rather, they were continuous. For instance, we were still continuing to revise the course content when we realize the need for a change. At the end of the first semester, we noticed an unnecessary component: reports on the problems of the Turkish Education System and the PTs' solutions for them. The main problem was that PTs were writing about general problems of the system; it is very hard to find something specific to chemistry/science education. Hence, we decided to exclude them from the course content and included another assignment to achieve our new goals related to the development of PTs' PCK. The new assignment involves observing experienced teachers' teaching on a specific chemistry topic while focusing on each PCK component.

Another example of modifications in the course content was related to CoRe use for planning. We learned from our previous experience that when PTs plan a lesson through the "lesson preparation method" they have difficulties. For instance, although PTs determined two or three objectives to teach in the lesson (e.g., to learn the pH concept, to be able to measure pH, and to be able to calculate the pH of an acid solution by the help of the ionization of acid), they assessed only one or two of them. Likewise, in many cases, PTs did not implement teaching and assessment strategies that were congruent with each other. This is most likely because they stated the objectives at the very beginning of the lesson plan; when they focus on the assessment part at the end of the plan format, they miss the objectives. Similarly, they determined the instructional strategies between the assessment and objectives, which is also vulnerable to be missed. Hence, we decided to use a different tool that has been used frequently and recently: the CoRe (e.g., Hume & Berry, 2011; Nilsson & Loughran, 2012). In the first semester, our practice with CoRe worked out satisfactorily. PTs also stated that it is very easy to see the relevance of all these PCK components through CoRe, which is a matrix including PCK components on the vertical axis and big ideas on the horizontal one. When the intersection of a PCK component and big idea is empty, PTs are easily able to realize inconsistency or that they neglected a point (e.g., assessing one of the big ideas, or mentioning what they expect students to understand about the big idea and be able to do). The new format of the lesson plan is more effective than the previous one, and PTs felt CoRe is more useful for their teaching. For example, during one of the mentoring sessions, a PT stated:

> I liked the new lesson plan format [CoRe] more since I had an experience on the previous one. Preparing, especially writing the previous lesson plan was taking more time and therefore I was able to focus less on designing the instruction. On the contrary, I spend more time on working on instruction and less on preparing lesson plan when I used the CoRe. (Meeting with PT on microteaching-1)

In the next semester, we continued to use CoRe in the practicum course. All the practicum and mentoring experience helped me to realize that the more PCK and reflection orientation is adopted, the more PTs gain from the practicum.

Knowledge of Instructional Strategies: Brenda's Vignette

Being a TA and mentor in this practicum course was a valuable experience for me in deepening my knowledge of instructional strategies. I learned that certain methods—explicitly introducing and using PCK, explicitly introducing CoRe, engaging more meaningful experiences of reflection, using Socratic dialog during mentoring, and having PTs use some modeled instructional strategies—were important contributions to PTs' learning about science teaching and their PCK. Before the revised practicum course experience, I used to think that it was enough to use microteachings with the feedback provided right after, present examples of cases where some instructional strategies are exemplified on some chemistry topics (i.e., engaging PTs in activities where they act like high school students), and take PTs' ideas on some pedagogical issues. With the change in my orientation and knowledge of learner, I expanded my knowledge of instructional strategies for teaching the practicum course.

First, I realized that PCK should be introduced explicitly at the beginning of the semester by the use of specific examples for each component of PCK. Before the self-study, PTs were planning and explaining their instruction superficially. Moreover, they were bringing activities together without considering whether their instructions assure students' meaningful learning of the topic. However, PTs started to use the language of PCK whenever they talk about their teaching and to successfully link their several knowledge bases (e.g., assessment and instructional strategy) to promote students' understanding of the topic as the participants became familiar with PCK constructs. Second, using CoRe as a lesson plan tool was another new strategy for me. At the beginning of the semester, we introduced CoRe by explaining what they were expected to do for each part of the plan. However, in preparing their first CoRes, PTs had difficulty in determining big ideas, what they expected to learn from students, stating difficulties relevant to each idea, and explaining the instructional strategy and assessment strategy that they planned to implement. Therefore, in the second semester of the practicum, we shared an example of a well-prepared CoRe, explaining the difficulties they can face. In this way, we made all the modeled teaching behaviors explicit. Using CoRe as a lesson plan tool was effective in moving PTs' teaching mode from "delivering the content" to "ensuring students' meaningful learning of the topic". PTs were able to translate their content knowledge into content knowledge for teaching. One of the PTs explained how CoRe use helped her as;

> Traditional lesson preparation method was restricting us. It was trying to stereotype our instruction under several headings such as objectives, instructional materials, etc. However, CoRe gives us freedom [while designing our instruction]. I realized its efficiency as I used CoRe during my lesson planning. (Meeting with PT on 3rd teaching practice)

Third, another instructional strategy that was congruent with our orientation was engaging PTs in various reflection opportunities. PTs wrote reflections on their own PCK development and on an experienced teachers' PCK. However, in their first attempts, they had difficulty in specifically evaluating their own development with respect to all PCK components. Therefore, we revised the reflection paper in a way to guide PTs when evaluating themselves by explicitly explaining each PCK component. For instance, we used the following questions for guiding PTs in evaluating their knowledge of learner components of PCK in the revised version of reflection paper: Did you know how to use learners' misconceptions and difficulties related to the chemistry topics in your teaching at the beginning of the semester? Did you notice any development about your knowledge of learners' misconceptions and difficulties? If yes, what are the practicum course components (e.g., mentoring) influencing the change? As a result of these reflection opportunities I realized that the more they reflect on their knowledge bases explicitly the more they can construct a robust knowledge base for teaching. PTs more frequently used the components of PCK in various settings whenever they talk about their or others' teaching through the end of the practicum.

Fourth, although I used to give suggestions to PTs when they planned a lesson during my previous experiences as a TA in practicum, I had never seen it as an instructional strategy since it was more like telling PTs what to do. However, the mentoring experience that I had during the revised practicum made me realize that it was an important instructional strategy in stimulating PTs' PCK development. Throughout the mentoring experience for two semesters, as a TA and mentor, I always asked PTs questions to guide them and help them think on their actions. For instance, during a mentoring meeting I asked one of the PTs, "How did you decide the order of the concepts you will teach? Is that appropriate for meaningful learning? Is there any evidence of concepts serving as a pre-requisite for others?" After those questions, she started to think and then realized that she needed to revise the order. These mentoring experiences helped me to recognize the importance of using Socratic dialog as an instructional strategy in the practicum course.

Finally, during the mentoring I always encouraged PTs to use some of the modeled instructional strategies they learned beforehand (e.g., 5E learning cycle). Since learning strategies enhance student learning, I asked PTs how they could promote students' learning, and which instructional strategy was helpful in this respect and compatible with their orientations (e.g., daily use of chemistry and scientific process skill development). Additionally, in some cases, PTs designed a lesson where they implemented phases of engage, explore, and explain without knowing the particular instructional strategy they intended to use. In that case, I asked what his/her instructional strategy was and how s/he could re-design it considering the 5E-learning cycle.

Knowledge of Assessment for Science Teachers' Learning: Sandi's Vignette

Knowledge of methods of assessing science teachers' learning (How to assess)

My experiences made me think about the way assessments were done and which assessment tools were used in the practicum course. After the realization of shortages of in lesson plan preparation (for details see the knowledge of aims, goals, and content of teacher education courses section in the results below), we looked for another tool and came up with a popular one in the science teacher education literature: CoRe. In addition, we used to give a test including multiple-choice items for assessing SMK at the end of the semester. Although SMK is a central knowledge domain for PCK development, we focus not only on SMK but PCK for teaching chemistry in the practicum. We spent some time to think, research, and reflect on it: how can we assess PCK for teaching chemistry at the end of the practicum? After studying on it, we decided to bring vignettes into play to capture PTs' PCK in the summative assessment, based on our findings in the teacher education literature (e.g., Veal, 2002). In the content-specific vignettes, we provided necessary information about an imaginary chemistry teacher and his/her classroom and school context. We also picked a particular topic (gases) and asked PTs about possible misconceptions and difficulties that learners may have about the topic. In another vignette, we focused on another topic (nuclear reactions) and asked PTs what pre-requisite knowledge is necessary for learning the topic.

Reports written on problems observed about the education system and solutions were used as a formative assessment tool in the old version of the practicum. We noticed that they were not very useful for us to uncover PTs' PCK. Therefore, we looked at the PCK literature to find out how PTs' PCK can be assessed. The literature has revealed the importance of reflection (Park & Oliver, 2008). Therefore, we replaced the reports with reflection papers, new tools for assessment in our practicum. Reflection papers allowed PTs to deeply analyze and focus on their knowledge of teaching. As a result, they become aware of their knowledge of teaching and improved their PCK for teaching. Finally, perhaps one of the most central assessment strategies for us was the mentoring meetings with PTs. Examining PTs' pre-CoRe (prepared before the meeting was held), making the collaborative CoRe preparation together, and observing microteaching and teaching together provided priceless feedback for me. It is interesting to note that I saw the instruction and assessment in the practicum separately in the past. However, we have learned how to get feedback for our actions in the practicum and PTs' PCK development simultaneously. In other words, mentoring meetings are both an instructional strategy that we implement and an assessment tool for us to capture PCK development of PTs throughout the practicum.

Knowledge of dimensions of science teachers' learning (What to assess)

As one of the last courses of the teacher education program, in the practicum we used to assess whether PTs utilize learner-centered and contemporary instructional strategies adequately. We also paid attention to classroom management and PTs' interaction with students in the class. PTs were supposed to submit the lesson plan that they prepared for microteaching and teaching in the partnership high school. We used to grade lesson plans by checking whether PTs addressed the items provided in the lesson plan format (e.g., objectives and instructional strategy). Moreover, we assessed SMK with a test (including multiple-choice items) administered at the end of the semester. When we compared and contrasted our focuses in the practicum and what we assess, the need for reforms in assessing PTs' knowledge and practice was realized, by the help of the PCK construct, which is the special amalgam of content and pedagogy (Shulman, 1986). The definition of PCK helped us realize that we failed to assess some of the PCK components and the interplay among PCK components.

In light of that diagnosis, many adjustments for what to assess were made in the course. First, we paid attention to assessing all PCK components (e.g., curriculum knowledge and knowledge of learner's difficulties and misconceptions) rather than only some of them (e.g., knowledge of instructional strategy). Second, we explicitly looked for the interplay among PCK components (e.g., how knowledge of assessment informs knowledge of instructional strategy). Third, instead of only having PCK as static knowledge, also viewing PCK as a professional knowledge for teaching was also valued in the practicum course, which was assessed by the use of three reflection papers. Finally, although we used to assess PCK by the use of microteachings, teaching practices, and lesson plans, I started to wonder how we could insert PCK into our summative assessment, conducted at the end of the course. (The details about including PCK assessment in the summative test were given in the previous section.)

Knowledge of purpose of assessing science teachers' learning (Why to assess)

The final point that I want to reflect on is the changes in our purpose of assessment in practicum. I have admitted that we mainly assessed for grading in past years, due to the fact that the practicum is almost the final course through which PTs have to show that they are able to teach chemistry, at least to some extent. I think we used to view ourselves as "gate-keepers" who check the tickets for passing through the door of the teaching profession. Moreover, when we compared and contrasted our aim and our practice, again we realized a contradiction between the two. Our aim is to help PTs develop PCK through the practicum course, but we have data only for the end point, rather than for the process. Our awareness of the situation made us head toward assessments on the journey. We collected data to capture PTs' PCK development throughout the practicum. Moreover, we also included a diagnostic assessment by the use of CoRe and asked PTs to prepare a CoRe on the "Rate of Reaction" topic (rate of reaction is very suitable to be studied due to the fact that it necessitates knowledge from chemistry and physics, and many instructional strategies can easily be applied) at the very beginning of the practicum. The use of CoRe was very useful in regards to determining the starting point and the weaknesses of PTs, and comparing and contrasting the starting point with the endpoint to get feedback for our new design.

CONCLUDING REMARKS

In this self-study, we collaboratively explored how re-designing a practicum course and serving as former TAs for the re-designed course contributed to our (three STEs) PCK and practices for teaching teachers within the framework of PCK. Serving as TAs, and more importantly reflecting on our knowledge and practices, stimulated our development of PCK for teaching teachers, and directed us to share our experiences with other STEs and teacher educators. Hence, we aimed to help our counterparts around the world to look at the mirror as we did and to reframe their thinking about teaching and practice through reflection and the PCK framework. In this section, we discuss our findings with regard to the nature and development of our PCK for teaching teachers, sources of the development, and how employing self-study was valuable for us in improving our knowledge and practices.

First, with regard to the nature of PCK, our study indicated the applicability of Magnusson et al.'s (1999) PCK model in characterizing and evaluating the quality of STEs' PCK for teaching teachers, which is consistent with the literature (Abell et al., 2009; Abell et al., 2010; Faikhamta & Clarke, 2013; Hanuscin et al., 2011; Hanuscin et al., 2012; Osmond & Goodnough, 2011). This model helped us to examine the individual components of PCK, which will be discussed later in this section.

The second point related to development of PCK was that although Osmond and Goodnough (2011) developed knowledge of learner and assessment more deeply than other PCK components, we experienced development in all components of PCK for teaching teachers, as was seen in others (Abell et al., 2009, Faikhamta & Clarke, 2013; Hanuscin et al., 2011; Hanuscin et al., 2012). Developing all PCK components may be explained by our extensive experience as TAs in practicum courses, which forewarned us about the problems faced in the practicum. Another possible reason is the interplay existing between our research and teaching practice. In other words, due to our familiarity with PCK literature as researchers, we are aware of what an effective teacher and teacher educator should know. Therefore, we paid specific attention to all PCK components for both teaching teachers and teaching science. Because of the ineffectiveness of previous practicum course in helping teachers to learn to teach, we first revisited our orientation and changed it to be reflective-driven and PCK-driven with the help of our knowledge on PCK research. Then, in light of these orientations, we revised the practicum course content and goals, the instructional strategies implemented in the practicum, and the purpose and type of assessment strategies implemented. Moreover, mentoring experiences enriched our knowledge of PTs, which also influenced other PCK components.

Third, Abell et al.'s (2009) model for the development of PCK for teaching teachers, proposes a continuum of professional learning that exists as STEs move through various learner roles: observer, apprentice, partner, independent instructor, and finally mentor. In this study, it seems that we took the role of partner by working as a team with the course instructor to re-design and implement the practicum course. However, our roles as learners of teacher education are much deeper than that; we have at least five-year experience as TAs, and already took the roles of observer and apprentice before this practicum course. These experiences as observer and apprentice formed the baseline of our previous role (partner) and current role (independent instructor), and hence more strongly stimulated our PCK development.

As STEs, we asked ourselves the following question: "If we had not employed the self-study on our knowledge and practice in the practicum, would it be possible to enrich our PCK for teaching teachers?" Definitely not! STEs generally do not have time to reflect on their knowledge and practices using a methodological approach (Osmond & Goodnough, 2011). Self-study enabled us to revisit our PCK for teaching teachers, develop components of PCK for teaching teachers with interplay among them, and more importantly align our practice with our knowledge by enacting what we learned into our teaching (Faikhamta & Clarke, 2013; Pinnegar & Hamilton, 2009). As Hanuscin et al. (2011) also experienced, self-study provided a systematic means through which we, as STEs, identified our deficiencies and took steps to address these in our PCK for teaching teachers. These improvements in our knowledge and practice can be counted as evidence for how self-study produces knowledge for the individuals involved (Dinkelman, 2003). By sharing our experiences with other STEs with the aim of helping them to revisit their knowledge and practices for teaching teachers, we indicated the knowledge available for other teacher educators.

IMPLICATIONS

This study has valuable implications for science education doctoral programs and research on science teacher education. Science education doctoral programs are generally missing an important piece—a careful consideration of preparing high quality STEs. Most of the doctoral students begin their profession without any systematic thinking about their PCK and practices for teaching teachers. If we did not intentionally analyze our PCK and beliefs by employing the self-study, the result would be the same for us. Therefore, doctoral programs in science education should promote the critical examination of TAs' knowledge and practices for teaching teachers. There might be several ways to accomplish this promotion. For instance, the instructors of teacher education courses may provide several tools for TAs to reflect on their own PCK for teaching teachers while TAs serve different roles as learners (e.g., observer, apprentice, and partner). Additionally, instructors and TAs may organize regular meetings where the instructor asks reflective questions about their knowledge and practice. TAs should keep journals throughout these meetings. Yet another way may be encouraging TAs to translate their research interest into their practice. Especially, supervisors may lead TAs in analyzing how their research agenda aligns with their practices of teaching teachers. The literature provides several other ways to stimulate the development of PCK for teaching teachers, such as participating in mentored internship activities (see Hanuscin et al., 2011), and enrolling in a course on designing and teaching science method courses (see Hanuscin et al., 2012).

Finally, although there has been an increasing effort in analyzing and defining PCK for teaching teachers, more research is needed on alternative tools that promote the development of PCK in that area. Most of the research on PCK for teaching teachers has been conducted by STEs as a result of their experiences with PTs. We do not know much about whether or not PCK for teaching pre– and in-service teachers differed to a certain degree. STEs can also study their PCK when designing professional development programs for in-service teachers. Another point that needs consideration is how the interplay among PCK components is built and enacted when teaching teachers, since most of the research on PCK focused on individual PCK components. We studied our PCK within the context of practicum, whereas other scholars studied their PCK development within the context of science teaching method course (e.g., Faikhamta & Clarke, 2013; Osmond & Goodnough, 2011). Investigating the development of PCK in other contexts (e.g., NOS, and instructional planning and evaluation courses) may be fruitful for drawing a clearer picture of PCK for teaching teachers.

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