J Sci Educ Technol (2010) 19:553–564
DOI 10.1007/s10956-010-9222-y

From PCK to TPACK: Developing a Transformative Model for Pre-Service Science Teachers

Syh-Jong Jang · Kuan-Chung Chen

Published online: 11 May 2010

Abstract New science teachers should be equipped with the ability to integrate and design the curriculum and technology for innovative teaching. How to integrate technology into pre-service science teachers' pedagogical content knowledge is the important issue. This study examined the impact on a transformative model of integrating technology and peer coaching for developing technological pedagogical and content knowledge (TPACK) of pre-service science teachers. A transformative model and an online system were designed to restructure science teacher education courses. Participants of this study included an instructor and 12 pre-service teachers. The main sources of data included written assignments, online data, reflective journals, videotapes and interviews. This study expanded four views, namely, the comprehensive, imitative, transformative and integrative views to explore the impact of TPACK. The model could help pre-service teachers develop technological pedagogical methods and strategies of integrating subject-matter knowledge into science lessons, and further enhanced their TPACK.

Keywords PCK · Peer-coaching · Pre-service science teachers · TPACK · Web-based learning

Introduction

A newly integrated curriculum scheme was implemented in primary and secondary schools of Taiwan in 2001. Such reform will inevitably affect the design and instruction of teacher education courses in universities. New science teachers should be equipped with the ability to integrate and design the curriculum and technology for innovative teaching (Jang 2006; National Research Council 1996). Current teacher education courses for pre-service teachers in Taiwan can be classified into two main categories: courses on subject-matter knowledge and those on professional knowledge of education (Jang 2007). However, many studies have pointed out that pre-service teachers who study science teaching knowledge, theories, methods and skills actually cannot cope with the real teaching situation (Jang 2007; Hashweh 2005). It has also been reported that the success of science teaching depends not only on the teachers' subject-matter knowledge but also on their personal understanding of students' prior knowledge and learning difficulty (Grossman 1990; Lederman et al. 1994). In addition, other factors of success include their own teaching methods and strategies, curriculum knowledge, educational situation, goal and value (Shulman 1987). In particular, the pedagogical content knowledge (PCK) of pre-service teachers is the main issue of the current teacher education revolution (De Jong et al. 2005; Grossman 1990; Shulman 1986).

Shulman's notion of PCK has attracted much attention and has been interpreted in different ways (Geddis et al. 1993; Grossman 1990). The foundation of science PCK is thought to be the amalgam of a teacher's pedagogy and understanding of science content such that it influences their teaching in ways that will best engender students' science learning. Initially, pre-service teachers separate subject-matter knowledge from general pedagogical knowledge. These types of knowledge are, however, being integrated as a result of teaching experiences. By getting acquainted with the specific conceptions of pedagogy and

S.-J. Jang (✉) · K.-C. Chen
Graduate School of Education, Chung-Yuan Christian University, 200 Chung-Pei Road, 32023 Chung-Li, Taiwan, R.O.C
e-mail: jang@cycu.edu.tw

ways of teaching, pre-service teachers start to restructure their subject-matter knowledge into a form that enables productive communication with their students (Lederman et al. 1994). According to Lederman et al. (1994), the development of PCK among pre-service science teachers is promoted by the constant use of subject-matter knowledge in different teaching situations. They suggest that PCK is developed through an integrative process rooted in classroom practice, and that PCK guides the teachers' actions when dealing with a specific subject matter in the classroom.

On the other hand, how to integrate technology into pre-service science teachers' PCK is another important issue. In contrast to the simple view of technology treated merely as a tool (Davis and Falba 2002; Jang 2008a, b; Watts-Taffe et al. 2003), the current issue emphasizes the connections and interactions between and among content, pedagogy, and technology (Mishra and Koehler 2006; Niess 2005). For technology to become an integral tool for learning, pre-service science teachers must develop an overarching conception of their subject matter with respect to technology and what it means to teach with technology—a technological pedagogical content knowledge (TPCK). In this case, knowledge about content (C), pedagogy (P), and technology (T) is central for developing good teaching. However, rather than treating these as separate bodies of knowledge, the current view emphasizes particularly the complex interplay of these three bodies of knowledge. TPCK is the integration of the development of subject-matter knowledge with that of technology and of teaching and learning knowledge (Niess 2005). However, the current teacher education programs often offer one basic technology course that pre-service teachers are required to take (Pope et al. 2005; Willis and Sujo de Montes 2002). This basic technology course should be the foundation for integrated activities in all courses (Pope et al. 2005). Pre-service teachers learn much about technology that is irrelevant to the development of their subject-matter knowledge and teaching knowledge. Similarly, they learn about learning and teaching irrelevant to both the subject matter and technology knowledge. In fact, pre-service teachers often learn about teaching and learning with technology in a more generic manner unconnected with the development of their subject-matter knowledge (Doering et al. 2003; Kim et al. 2007; Lewis 2006; Rosaen et al. 2003; Vannatta and Fordham 2004).

Many related studies indicated that the instructional models related to teaching experience are important for PCK development (De Jong et al. 2005; Loughran et al. 2004; Van Dijk and Kattmann 2007; Van Driel et al. 2002). However, there are few empirical researches that integrate technology into the PCK of pre-service science teachers (Angeli and Valanides 2009; Koehler et al. 2007; Mishra and Koehler 2006; Niess 2005). Therefore, the purpose of this study was to develop a transformative model for enhancing the TPACK of pre-service teachers in a science teacher education course.

Theoretical Framework

Pre-service Science Teachers' PCK with Technology

Shulman (1987) regarded the knowledge base for teaching as comprising seven categories, three of which are content related (subject-matter knowledge, PCK, and curriculum knowledge). The other four categories refer to general pedagogy, learners and their characteristics, educational contexts, and educational purposes. PCK involves the transformation of other types of knowledge (subject matter knowledge, pedagogical knowledge, and knowledge of context) into viable instruction (Abell 2008) so that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice. Science teachers' PCK is deeply personal, highly contextualized and influenced by teaching interaction and experience (De Jong et al. 2005; Van Dijk and Kattmann 2007; Van Driel et al. 2001). Mulholland and Wallace (2005) suggested that science teachers' PCK requires the longitudinal development of experience as they develop from novices into experienced teachers. Van Driel et al. (2002) investigated the development of PCK within a group of 12 pre-service chemistry teachers and claimed that the subject-matter knowledge was a prerequisite for the development of PCK and that PCK developed in the actual teaching experience of teachers. Thus, pre-service teachers may derive PCK from their own teaching practice as well as from schooling activities. Many scholars suggest that PCK is developed through an integrative process rooted in classroom practice, and that PCK guides the teachers' actions when dealing with a specific subject matter in the classroom. In order to monitor the development of PCK, Van Driel et al. (2002) chose a multimethod approach and qualitative in-depth study. The analysis of all data (both written and verbal) focused on the identification of regularities or patterns in the statements made by the respondents. This measuring PCK approach would help us design this study.

In previous studies, science education researchers have emphasized the importance of supporting professional development of pre-service teachers for technology integration (Flick and Bell 2000; Jang 2008a, b; Kim et al. 2007). In the communities of teaching practice, electronic dialogue on classroom issues has been shown to support effective reflection and shared practical knowledge among pre-service teachers (Edens 2000; Jang 2008a; Levin 1999). The characteristics of online communities fit the PCK development of many pre-service teachers. The community-support needs expressed by teachers included overcoming isolation from and sharing experiences with peers, providing equal access to PCK development opportunities and ongoing support for the change process, sharing tools for professional discourse, and allowing for asynchronous communication which is more amenable to in-depth, reflective conversation (Dalgarno and Colgan 2007; Shotsberger 2000). This approach is socially constructivist in nature because learning depends upon constructing personal knowledge for teaching through social interactions in a community of practice (Jang 2007; Vygotsky 1978). PCK is collaboratively constructed between individuals whence it can be appropriated by each individual. This form of thinking and dialogue among pre-service teachers aligns reflection closely with practice. Pre-service teachers can post reflective thoughts and queries on personal practice to a specific website for practical feedback from others in the community (Jang 2008a). Electronic forums help support this sharing and reflection among pre-service teachers that in the past could only occur in face-to-face meetings (Upitis and Russell 1998).

Technological Pedagogical and Content Knowledge

TPCK highlights the connections and interactions among content, pedagogy, and technology (Mishra and Koehler 2006). Furthermore, this complex among the three kinds of knowledge was reframed as Technological Pedagogical And Content Knowledge (TPACK) describing it as the total package required for integrating technology, pedagogy and content knowledge in the design of curriculum and instruction (Niess et al. 2009; Thompson and Mishra 2008). TPACK represents a new direction in understanding the complex interactions among content, pedagogy and technology that can result in successful integration of technology in the classroom. TPACK is an extension of PCK and is primarily achieved when a teacher knows how technological tools can transform pedagogical strategies and content representations for teaching specific topics. Koehler et al. (2007) stated TPACK is a situated form of knowledge required for the intelligent use of technology in teaching and learning.

> At the heart of TPCK is the dynamic, transactional relationship between content, pedagogy, and technology. Good teaching with technology requires understanding the mutually reinforcing relationships between all three elements taken together to develop appropriate context-specific strategies and representations (Koehler et al. 2007, p. 741).

Good computer skills are not enough for pre-service science teachers to give technology-mediated lessons. Some studies showed that pre-service teachers who had good computing skills with specific training in uses of computers designed better technology-mediated lessons than those who also had good technical skills but no specific training in the educational uses of computers (Angeli and Valanides 2005; Angeli 2005; Valanides and Angeli 2006, 2008). They concluded that teacher educators need to explicitly teach how the unique features can be employed to transform a specific content domain for specific learners, and that teachers need to be explicitly taught about the interactions among technology, content, pedagogy, and learners. Schaverien (2003) used a web-delivered technology and science education context in which pre-service teachers could develop their ability to recognize, describe and theorize learning. This e-learning environment aimed to use advanced technologies for learning, to bring about larger scale improvement in classroom practice than has so far been affected by direct intervention through teacher education. Pre-service teachers' short, intensive engagement with the Generative Virtual Classroom during their practice teaching was examined. Findings affirmed the worth of this e-learning system for teacher education and the power of a biologically based, generative theory to make sense of the learning that occurred.

Schmidt et al. (2009) developed and validated an instrument designed to measure pre-service teachers' self-assessment of their TPACK and related knowledge domains included in the framework. Angeli and Valanides (2009) proposed five criteria for assessing TPACK in designing instruction with technology: (1) identification of topics to be taught with technology in ways that signify the added value of tools, such as, topics that students cannot easily comprehend, or topics that teachers face difficulties in teaching effectively in class; (2) identification of representations for transforming the content to be taught into forms that are comprehensible to learners and difficult to be supported by traditional means; (3) identification of teaching strategies, which are difficult or impossible to be implemented with traditional means; (4) selection of appropriate computer tools and effective pedagogical uses; and (5) identification of appropriate strategies to be combined with technology in the classroom, which includes any strategy that puts the learner at the center of the learning process. They assessed each criterion with a numerical scale from 1 to 5. Two experts in instructional technology, with the help of content experts, evaluated all lesson activities using the criteria, as well as students' self- and peer assessments. Angeli and Valanides' (2009) quantitative measure along with other scales created by Schmidt et al. (2009) are useful to examine pre-service teacher's TPACK in a general manner. However, the quantitative measures are relatively weak in portraying the subtle interrelationships among technology, pedagogy and content in the context of science teaching and learning. Furthermore, the quantitative measures are hardly used to assess and describe how pre-service teachers develop their TPACK. Therefore, in this study, we transformed Angeli and Valanides' (2009) five criteria into written assignments for assessing the development of TPACK for pre-service science teachers. We used a multimethod approach and qualitative in-depth study, and developed a transformative model of integrating technology and peer coaching to examine the impact on TPACK of pre-service science teachers.

Peer Coaching

Peer coaching provides a community of practice defined as a group of individuals, who share such commonalities as interests, knowledge, resources, experiences, perspectives, behaviors, language, and practices (Lave and Wenger 1991). Bowman and McCormick (2000) suggested that through social interaction, active learning evolves and each participant interprets, transforms, and internalizes new knowledge. Within the framework of peer coaching, such collaborative discussions allow individuals to develop their own perspectives and to model strengths for others. Pierce and Hunsaker (1996) stated that peer coaching not only increases collegiality, but also enhances each teacher's understanding of the concepts and strategies of teaching, and sustains the movement toward restructuring the traditional evaluation efforts by strengthening the ownership of change. Jenkins et al. (2005) suggested peer coaching as a means of developing PCK because the approach is situated in the context wherein teaching and learning occur. Peer coaching can increase reflective practice, aid implementation of teaching models and instructional strategies, and enhance classroom management and development of PCK (Jenkins and Veal 2002; McAllister and Neubert 1995).

Joyce and Showers (1982) introduced peer coaching as a component of teacher training. A fully elaborated peer coaching model with a planning and implementation consists of four elements: (1) the study of the theoretical basis or rationale of the teaching method; (2) the observation of demonstrations by persons who are experts in the teaching method; (3) practice and feedback in relatively protected conditions, and (4) coaching one another to assist the new method to be incorporated into day-to-day teaching style. In their more recent work, Joyce and Showers (1995) expanded their view of peer coaching, emphasizing learning through collaborative planning, development and observation of instruction. They stressed the importance of a non-hierarchical relationship between peers working and learning collaboratively to improve their teaching.

Developing a Transformative Model

Shulman (1987) proposed that PCK development might pass through the processes of comprehension, transformation, instruction, evaluation, reflection and new comprehension. In this study, peer coaching can be described as a collegial approach to the analysis of teaching aimed at integrating new skills and strategies in classroom practice (Joyce and Showers 1995). This study revised the instructional model proposed by Joyce and Showers (1995) into the transformative model of TPACK-COPR (TPACK Comprehension, Observation, Practice and Reflection) as shown in Fig. 1. This model comprises four main activities: (1) comprehension of TPACK, (2) observation of instruction, (3) practice of TPACK, and (4) reflection of TPACK. The on-line assisted learning of the PCK e-learning system was the platform for implementing the TPACK-COPR model.

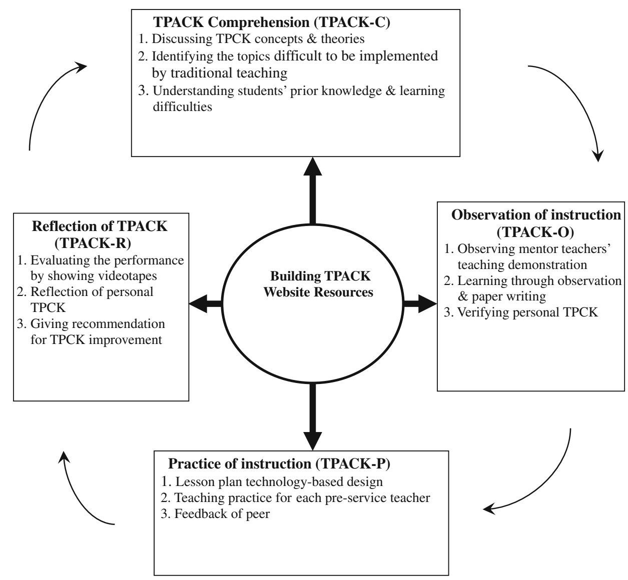

Fig. 1 A transformative model of TPACK-COPR

First, the peer-coaching model starts at the study of the theoretical basis or rationale of the specific content teaching method. The understanding includes studying on the topics of textbook and TPACK articles in teams, and pre-service teacher would describe his/her understanding of the subject-matter knowledge of the specific subject content unit. The analyses and discussions on these PCK and TPACK research articles also contribute to the science teacher's PCK of useful instructional strategies for overcoming secondary students' learning difficulties (Van Driel et al. 2002) or identifying some topics difficult to be implemented by traditional means. Second, in order to integrate TPACK theories and practice, the second main activity was to observe experienced mentor science teachers. Pre-service teachers should observe the teaching and note their skills according to the learned TPACK theories and strategies. After watching the demonstration, pre-service teachers take turns to give their comments and suggestions. Third, pre-service teachers learn to design technology-based lesson plans and apply it to teaching practice. After the practices, the peer would analyze and comment on the pros and cons of their teaching. Many related studies indicated that the choice of instructional model related to teaching experience was important for PCK development (De Jong et al. 2005; Gess-Newsome and Lederman 1993; Loughran et al. 2004; Van Driel et al. 2002). Finally, each pre-service teacher should show the videotapes of his/her teaching to share his/her teaching experience with others. This teaching practice can stimulate teachers' self-reflection. To reflect is to think about where you have been and/or what has happened in order to clarify your experience (Vidmar 2006). In this study, the researchers used the transformative model of integrating technology and peer coaching to develop the TPACK of pre-service science teachers.

Research Methodology

Context and Participants

The context of this study was a teacher education course—"Pedagogical Content Knowledge in Science and Technology" designed for pre-service teachers on how to design lesson plan and apply teaching theories and strategies to practice teaching in order to gain teaching experience, pedagogical knowledge, teaching methods and technology. However, the current pre-service teacher programs emphasized teaching theories and methods rather than actual implementation or technology-based application in teaching. In this study, the core course lasted 18 weeks and ran for 2 h every week throughout the whole semester. The study was designed as a four-stage process of the transformative model. The participants included a single instructor and a total of 12 pre-service teachers. The instructor, who was the primary researcher, specialized in science teaching methods and strategies. These pre-service teachers were selected for a 2-year teacher education program from the Science College at the University. There were five males and seven females, ranging in age from 19 to 27 years. They were all interested in becoming a science teacher in secondary schools in the future. To be able to participate in this program, the students were qualified in (a) firstly, the academic record of the students had to reach more than 30 percent in their classes, (b) they had to pass the paper examination which included basic science concepts and knowledge of education, (c) they had to pass the oral examination which included role play, instant response and vision of education.

TPACK On-Line Resources and Implementation

The researchers built an on-line assisted learning of the TPACK system to be the platform for implementing the TPACK-COPR model. The online materials for each part of this course contained contents, slides and online references. The setting of online the teaching system included the curriculum information and resources, forum and online discussion board. Prior to the official implementation of the web-assisted learning network, pre-service teachers would become familiar with the implementation and functions of the hardware and software and reinforce the support in either hardware or software to prevent possible technical problems. There were 12 participants in this study, which were divided into three groups with four participants in each group. To see how well pre-service teachers learned and retained their attendance online, the instructor would evaluate the pre-service teachers in two ways, individually and within the group, every other week. For individual task, the pre-service teacher had to learn to collect data individually, participate in the discussion and post their comments online to share with other peers at least twice each week. For group task, team members would post the results regarding the PCK group homework on the website after they reached consensus through discussions.

The four activities of the TPACK-COPR model were integrated into the whole course through four stages as discussed in the following.

Stage One: TPACK Comprehension

During the first 4 weeks, the course outline, teaching method, and method of evaluation would be introduced. This stage included the main activity for understanding the content of PCK and TPACK. The instructor introduced general concepts of e-learning including its definitions, benefits, limitations, and possible applications (e.g., drills, tutorials, games, simulations, and online learning). Next, a variety of e-learning tools were brought to them to expand their conceptions of technology's properties and affordances. These tools can be categorized into: (1) multimedia (graphic, audio, video, and 2D/3D animation) authoring tools, (2) presentation tools (e.g., Power Cam and Articulate Presenter), (3) communication/social tools (e.g., Skype and Facebook), (4) collaboration tools (e.g., Google Documents and Youtube), (5) organization/mapping tools (e.g., Inspiration & Visio), and (6) metacognition/planning tools (Blog & Timeline). Resources for shareware/freeware download and tutorials for e-learning software were offered in class. Pre-service teachers were encouraged to fish by themselves, which means exploring and playing with a variety of software, and determining those that are most appropriate for their prospective teaching.

Moreover, the pre-service teachers were divided into collaborative teams, each of which comprised four people. The instructor might let pre-service teachers study the content of PCK and TPACK in teams. Every pre-service teacher would describe his/her understanding of the subject-matter knowledge of the specific subject content unit in his/her journal. After the group discussion and examination, pre-service teachers would note down the knowledge of students' understanding and preconceptions of these topics. Finally, pre-service teachers would post the results of team discussions regarding the PCK on the website as a routine task. During the first stage, they were asked to answer the following question:

> Assignment 1: What science topics difficult to understand do you remember from your earlier experiences as a secondary student, as a university student, or from your previous teaching practice?

The pre-service teachers wrote down their recollections individually, which were then discussed by all. After the discussion and examination in a group, pre-service teachers would note down their responses in their reflective journals.

Stage Two: TPACK Observation

In order to learn more TPACK theories and practice from Week 5 to Week 6, the second main activity was to have two experienced mentor science teachers demonstrate their teaching of integrating technology with respect to the unit—"Density and Buoyancy". These mentors were invited by the instructor and proved their teaching good enough for technology demonstration. The pre-service teachers should observe the teaching and note their skills according to the learned PCK theories and strategies. Furthermore, pre-service teachers not only prepared a written report and posted it on the website, but also discussed about the integration of mentor teachers' teaching strategies or methods according to their acquired TPACK. In this stage, the pre-service teachers were asked to write down their individual responses to the following assignment:

> Assignment 2: What teaching representations or strategies for understanding these topics you may use to transform science content into forms that are pedagogically powerful?

Again, all written responses were collected, and the subsequent group discussion was recorded on their reflective journals.

Stage Three: TPACK Practice

The third activity was carried out from Week 7 to Week 15. The pre-service teachers learned to make lesson plans and applied innovative teaching methods and strategies to teaching practice. Every pre-service teacher of each group would integrate computer activities with appropriate topic-specific pedagogy to teach individually for about 30 min to the whole class. They might integrate the previously learned TPACK strategy and skills by observing mentor teachers' teaching. For example, a pre-service teacher used a buoyancy-meter to demonstrate the buoyancy phenomena of water and utilized a computer to assist this demonstration. After the trial teaching, the other peer and the instructor would criticize and analyze the observation about teaching strategies and related teaching activities used by the pre-service teacher. Furthermore, in this stage, each group would make two demonstrations of their teaching to the whole class, and each demonstration lasted about 40 min. The pre-service teachers needed to design the lesson plan with technology collaboratively, and integrate computer activities with appropriate topic-specific pedagogy. Every pre-service teacher of each group could help and learn from each other. The pre-service teachers also needed to have their teaching performance videotaped. In addition, they would write down their own thinking and raise questions in the online discussion forum. In the end, they had to post their comments online to share with other peers to learn from each other. Finally, each group also required to present their instructional website as their final project. When evaluating the final project, special attention was given to *how* they integrated content, pedagogy, and technology in a course element, as well as *why* they decided to implement such integration.

> Assignment 3: (a) How do you select technology tools with pedagogy to afford content transformations of these topics in lesson design? Explain your choice.

Again, all written responses were collected, and the subsequent group discussion was recorded on their reflective journals.

Stage Four: TPACK Reflection

The fourth activity on reflection and modification lasted from Week 16 to Week 18. After completing the teaching practice, the instructor and pre-service teachers would see the videotapes of their teaching. Pre-service teachers shared with others their teaching experience, and wrote the reflection in their journals. The purpose of this activity was to evaluate pre-service teacher's teaching performance. Pre-service teachers of each group would take turns to reflect on their own practice; followed by comments from other peers. Finally, the instructor would give appropriate feedback and comment on their demonstration and practice. In this stage, the effects of such integration on PCK and ability of capitalizing technology among pre-service teachers were evaluated. Furthermore, the reflective stage would help them self-examine their current lesson plan design and teaching practice in order to modify future teaching practice.

> Assignment 4: Describe your TPACK development after you went through the whole process of the transformative model?

All written assignments were collected and, again, the concluding group discussion was recorded on their journals.

Data Collection and Analysis

To monitor the development of TPACK during this study, data were collected at specific moments that were closely associated with the design of transformative model. The data collected consisted of: (a) the written assignments of each individual pr-eservice teacher to the questions and assignments included in the four parts of the model; (b) the reflective journal written by the pr-eservice teachers through the overall process of the model and this course; and (c) the online data included questions and content of the online discussions between the instructor and pre-service teachers, online submission of homework and feed-back, communication of personal problems and responses through emails and other related online information; and (d) the video-recordings of lessons about the chosen topics that took place during the teaching practice. These recordings were transcribed verbatim; and (e) the interviews which served to gain a deeper understanding of each pre-service teachers' conceptions. The interview was conducted after implementing the model, which was to explore the extent of transformation of pre-service teachers' TPACK. It included the understanding of learner's knowledge, the changes in teaching knowledge or skills, the abilities of implementing technologies, and the overall changes in TPACK. According to the information gathered from the interviews, the researchers wished to discern the possible discrepancies of their views written down in the written assignments, online articles and journals.

The inductive data analysis employed in this study utilized a qualitative framework that allowed the researchers to build patterns of meaning from the data (McMillan and Schumacher 2001). Four phases, as described by McMillan and Schumacher, were employed for the analysis of the transcripts: (1) continual discovery throughout the research in order to tentatively identify patterns; (2) categorizing and ordering data; (3) refining patterns by determining the trustworthiness of the data; and (4) synthesizing themes. Accordingly, the researchers assigned the changes found from individual respondents to these categories, resulting in a numerical overview of the results. A constant comparative method was utilized to compare the written assignment data and other data (reflective journals, online data and videotapes) with the categories generated (Strauss 1987). The data were first collected, coded, compared and then organized into different categories. Then the data were interpreted according to the categories.

Results and Discussion

Throughout this section, this study refers to pre-service teachers using names that are different from their real names. Female names, however, refer to female teachers and male names to male teachers. According to the research purpose, this study developed a transformative model of integrating technology and peer coaching to examine the impact on TPACK of pre-service science teachers. Therefore, the results were divided into the following four categories.

1. Pre-service science teachers realized that it was difficult to implement traditional instructional strategy on some abstract units; thus, they would tend to incorporate powerful pedagogy.

In the first writing assignment, there were some abstract science units (e.g. electric potential and buoyancy) from their earlier experiences as secondary school-boys or -girls, and as university students, or from their previous teaching practice (Assignment 1). Especially, some of the pre-service teachers thought that it was not easy to introduce "electricity", including the concept of "electric current" and "electric potential" with traditional instructional strategy. There are few models in traditional instruction which can elaborate that high and low electric potential tend to be dependent on currents. It is also abstract to explain the in relation to the concept for "Ampere's right-hand rule". Three of the pre-service teachers stated in first writing assignment:

> In my opinion, electricity is abstract and it is difficult to introduce the concept of electric potential using traditional instruction. (Mary, written assignment).
> It is hard to describe the concept of "electricity", especially in relation to the concept of "electric current". (Betty, written assignment).
> Although I try to adopt "Ampere's right-hand rule", it is difficult to explain the relationship between electric current and electromagnetic direction to the students. (Peter, written assignment).

However, in the second written assignment- "transform science content into forms that are pedagogically powerful" (Assignment 2), pre-service teachers considered that they could use life experience examples to describe the abstract concept and overcome students' learning difficulties. In this study, pre-service teachers acquired the opportunities to transform abstract knowledge into their teaching design. They have to see some connection between their science learning and life experiences, and knowledge is accumulated from these life experiences. Thus, pre-service teachers might teach the science content knowledge by transforming real examples into students' practical experience for a better representation. Three of the pre-service teachers stated:

> I use life experiences which can be observed easily to explain the concepts. For example, the electricity is like the water drop. The electric current is like the water current. The electric potential is like the water potential of a reservoir which can lead the movement of the electric current. (Mary, written assignment).

> I use the water current of a faucet to explain the concept of the electric current. The high or low position of a water pipe is like the electric potential. The proportion of the water current from the faucet is like the electric current. (Betty, written assignment).

> I made a simple circuit including a dry battery, a bulb, an electric wire, and an Ampere. Manipulating the circuit lets students have deeper impressions of the concepts of the electricity and electric current. I also extend the working principles such as daily electricity, or generator. (Amy, written assignment).

2. Observing experienced science teachers helped pre-service teachers imitate and apply instructional strategies, films and animations in their teaching.

The difficulty which pre-service teachers encountered was how to present the science formula and content knowledge to students in an efficient way. The initial process of mentor teaching observation in the study could provide help for an individual who did not have any teaching experience. Pre-service teachers thought that they had learned to design activities with instructional strategies, films and animations after they observed the mentors' teaching. Further, it helped pre-service teachers imitate some practical technological pedagogical strategies and organize their personal thinking. Three of the pre-service teachers stated:

> Observing an experienced teacher can help me design a teaching activity for explaining the abstract buoyancy formula. I use a real-life object, "clay", put in water and let students experience the modified clay shape show its different buoyancy in my teaching practice. (Caleb interview).

> I created a multimedia video-recording to illustrate the concept of density and its applications. This idea was inspired by the observation from a mentor teacher's teaching. (Dick interview).

> The observation helped me a lot in developing my instructional strategy. After explaining the important concept of electric current, I will provide some computer stimulation activities for the students to enhance their understanding. (Ann online data).

"Observation" is a positive model that allows pre-service teachers to benefit from each other. Each pre-service teacher has his/her own instructional model, and considers it the best. Through observation, pre-service teachers can reflect on their limitations, as suggested in the saying, "seeing another better than oneself, one tries to equal him." With peer observation and demonstration, pre-service teachers can think about improving their future instructions.

3. This model offered pre-service teachers practical opportunities to select and transform technology tools with science pedagogy in lesson design.

Most of the pre-service teachers thought that they were equipped with science content knowledge. However, the science content knowledge seems to be objective to them before the teaching practice experience. In this study, pre-service teachers acquired the opportunities to transform theoretical formula and knowledge into their teaching practices. After focusing on pedagogy, pre-service teachers wrote down and select technology tools with science pedagogy to afford content transformations of these topics in lesson design (Assignment 3). Pre-service teachers found that they understood better the topic when integrated into technology-based design via web-based learning. In the process of interactive learning, they gradually developed professional knowledge to choose powerful and concrete pedagogy and proper technology tools (Flash, video-tapes, and Blog) in their lesson plan. With realistic animation and multiple teaching strategies, students would have higher learning interests in understanding the principle of electric potential or degree of electric current. Three of the pre-service teachers stated:

> I use the water current which students had already learned to explain the electric current. Then I design the lesson plan by using the flash to simulate the movement of the electric current. Finally, I draw the circuit and mark the relation of the electric current, electric potential, and the electric resistance. (Bee interview).

> I first design the lesson plan by using the electric current video-clips from the Internet. Then use interactive strategies through group discussion, views exchange and experience sharing. (Paul online data).

> I design the lesson plan by applying the learning forum from the blog. Students can discuss the concepts of the electric current and answer the questions. The conflict of the cognition can promote peers conversation. (Amy reflective journal).

4. Pre-service teachers reflected that they had learned TPACK and how to integrate technologies with teaching.

These pre-service teachers reflected that they had learned how to integrate technologies with teaching through the transformative model and the web-based learning environment and related websites (Assignment 4). They would connect the television in the classrooms with their notebook computers and support their instruction by online resources; they could describe some abstract units (e.g. electric potential and buoyancy) by visual interactive model and animation. In this study, through peer coaching and online discussion, pre-service teachers could exchange their ideas and opinions when they had questions about the course. This provided them with an avenue to obtain instant feedback and learn related pedagogical content knowledge with technology. Three of the pre-service teachers stated:

> When I explain "Ampere's right-hand rule", I try to make students understand the relationship between electric current and electromagnetic direction by the animation of the experiment upon the principle. Finally, I will enhance the students' memory by my right-hand explanation. (Sue interview).

> I would like to use TV programs from the Discovery channel and Internet resources in my teaching with respect to electricity. (Grace online data).

> To illustrate buoyancy of liquid, I present the concept using the Flash program, which has an immediate effect on students' comprehension. What a magic effect of the application of Flash! Students learned by observing the phenomena of buoyancy from the presentation. (Robert interview).

> The model helped me use computer-assisted teaching method to interpret the subject matter in the unit of density in a more comprehensible way. (Mary reflective journal).

Implications and Conclusion

This study provided empirical evidences showing that the transformative model did have some impact on pre-service teachers' TPACK in particular topics of subject matter. However, there have been few studies on TPACK and the relation between technology-based model and PCK of pre-service teachers (Angeli and Valanides 2009; Koehler et al. 2007; Niess 2005). According to the transformative model, this study expanded four views namely, the comprehensive, imitative, transformative and integrative views to explore the development of TPACK. From the comprehensive view, the model helped pre-service teachers understand better their TPACK. Pre-service science teachers understood clearly that it was difficult to implement traditional instructional strategy on some abstract units (e.g. electric potential, current, buoyancy or density); thus, they would tend to incorporate technology in the instruction. In this study, analyses and discussions on these PCK research articles also contributed to the pre-service teachers' PCK of useful instructional strategies for overcoming secondary students' learning difficulties (Van Driel et al. 2002). In general, reading and discussing the paper had triggered the development of pedagogical knowledge for at least some of the participating pre-service teachers. By getting acquainted with students' specific conceptions and online ways of learning, pre-service teachers might use some technology-based examples to motivate students for learning. If technology could be properly integrated in some units (e.g. electric potential or buoyancy), the animation and course explanation in detail could allow students to comprehend the meanings. This would restructure their abstract subject-matter knowledge into an easy understandable form that enables productive communication with their students (Lederman et al. 1994).

According to the imitative view, pre-service teachers have learned to imitate and develop TPACK by observing mentor teachers. Pre-service teachers can learn how to apply technology by observing mentor's usage of technology. This way of learning new experience by observing others is called "vicarious learning" (Bandura 1986). It is suitable for pre-service teachers with no real teaching experience to learn new technology. In this study, specifically, observing an experienced mentor teacher can help pre-service teachers design a teaching activity for explaining the abstract buoyancy formula. They have learned how to use instructional strategies, internet resources, films and animations in the instruction. Learning technology by the design approach is a constructivist approach that sees knowing as being situated in action and co-determined by the peer interaction environment (Brown et al. 1989; Koehler et al. 2007; Young 1993). Furthermore, pre-service teachers in the teaching model utilized some practical TPACK in the classroom while the traditional teacher education class focused on self-construction of knowledge.

According to the transformative view (Angeli and Valanides 2009; Gess-Newsome 1999), TPACK is considered as a distinct set of knowledge constructed from other forms of teacher knowledge. Pre-service teachers' knowledge of representations and teaching strategies had benefited and developed in the actual teaching experience. This strong impact of teaching experiences is consistent with the findings of other scholars (De Jong et al. 2005; Grossman 1990; Lederman et al. 1994). Pre-service teachers developed their TPACK, which has been described as the transformation of several types of knowledge for teaching (Magnusson et al. 1999). Since the science formula and theories learned by the traditional teaching method were usually considered objective and abstract, pre-service teachers found it easier for them to combine the theory with practice and further organize their subject-matter knowledge through the innovative teaching model. It was possible for pre-service teachers to connect their professional subject-matter knowledge with their teaching methods (Lederman et al. 1994). According to Geddis (1993), the transformation turned pre-service science teachers' subject-matter knowledge into teachable content knowledge. Pre-service teachers might use computer-assisted teaching method to explain the important concepts by designing some exercises for students to experiment with the concepts they acquired.

According to the integrative view, TPACK is not considered a distinct form of knowledge, but a body of knowledge, which is made up of other forms of teacher knowledge that are integrated during the act of teaching (Angeli and Valanides 2009). The instruction model helped pre-service teachers integrate appropriate strategy and technological application efficiently in their teaching practice. In this study, using methods of online discussion, pre-service teachers could exchange their ideas and opinions. This provided them with an avenue to obtain instant feedback and learn related technology knowledge. It increased the opportunities for communication, explanation and exchange of their experiences with peers (Dalgarno and Colgan 2007). In other similar studies, the researchers learned that pre-service teachers could enhance the application of technology and knowledge by integrating technology into teacher education courses (Angeli 2005; Jang 2008a).

In conclusion, the model succeeded in contributing to the development of TPACK of the participating pre-service teachers. That is, it turned out to be useful to start the model with activities focusing on explicating pre-service teachers' initial knowledge of some abstract units difficult to be implemented by traditional instructional strategy, and expanding these notions by analyzing and discussing fragments from TPACK comprehension activities. The activity also appeared to stimulate their thinking about potentially useful instructional technological strategies. Next, the initial process of teaching observation in the study could provide help for an individual who did not have any teaching experience. It helped pre-service teachers imitate some practical TPACK, and organize their personal thinking to verify the theories in textbooks. The mentors' approach and involvement indicated their potentially strong impact on the development of pre-service teachers' TPACK. Then, it was important that pre-service teachers were provided with authentic opportunities to experiment with teaching approaches. In this context, some of them appeared to have focused on the design of their instructional approach, whereas others had concentrated on how to transform technologies with teaching through the web-based learning environment. Finally, writing a reflective lesson report and discussing their videotaped performance with each other turned out to be useful in helping pre-service teachers explicate, and further integrate their TPACK about students' learning difficulties, instructional strategies and technology. Therefore, not only was the integration of technology and an innovative model a way to develop science pre-service teachers' TPACK, it was also a good teaching strategy for promoting the utilization of instructional technology in teaching for pre-service teachers.

References

Abell SK (2008) PCK twenty years later: does it remain a useful idea? Int J Sci Educ 30:1405–1416

Angeli C (2005) Transforming a teacher education method course through technology: effects on pre-service teachers' technology competency. Comput Educ 45:383–398

Angeli C, Valanides N (2005) Preservice teachers as ICT designers: an instructional design model based on an expanded view of pedagogical content knowledge. J Comput-Assist Learn 21(4): 292–302

Angeli C, Valanides N (2009) Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: advances in technological pedagogical content knowledge (TPCK). Comput Educ 52:154–168

Bandura A (1986) Social foundations of thought and action: a social cognitive theory. Prentice-Hall, Englewood cliffs

Bowman C, McCormick S (2000) Comparison of peer coaching versus traditional supervision effects. J Educ Res 93(4):256–264

Brown JS, Collins A, Duguid P (1989) Situated cognition and the culture of learning. Educ Res 18(1):32–42

Dalgarno N, Colgan L (2007) Supporting novice elementary mathematics teachers' induction in professional communities and providing innovative forms of pedagogical content knowledge development through information and communication technology. Teach Teacher Educ 23:1051–1065

Davis KS, Falba CJ (2002) Integrating technology in elementary preservice teacher education: orchestrating scientific inquiry in meaningful ways. J Sci Teacher Educ 13(4):303–329

De Jong O, Van Driel JH, Verloop N (2005) Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. J Res Sci Teach 42(8):947–964

Doering A, Hughes J, Huffman D (2003) Preservice teachers: are we thinking with technology? J Res Educ 35(3):342–361

Edens KM (2000) Promoting communication, inquiry, and reflection in an early practicum experience via an on-line discussion group. Action Teacher Educ 22:14–23

Flick L, Bell R (2000) Preparing tomorrow's science teachers to use technology: guidelines for science educators. Contemp Issues Technol Teacher Educ 1(1):39–60

Geddis AN (1993) Transforming subject-matter knowledge: the role of pedagogical content knowledge in learning to reflect on teaching. Int J Sci Educ 15:673–683

Geddis AN, Onslow B, Beynon C, Oesch J (1993) Transforming content knowledge: learning to teach about isotopes. Sci Educ 77(6):575–591

Gess-Newsome J (1999) Pedagogical content knowledge: an introduction and orientation. In: Gess-Newsome J, Nederman NG (eds) Examining pedagogical content knowledge. Kluwer, Dordrecht, pp 3–17

Gess-Newsome J, Lederman NG (1993) Preservice biological teachers' knowledge structures as a function of professional teacher education: a year-long assessment. Sci Teacher Educ 77(1):25–43

Grossman PL (1990) The making of a teacher: teacher knowledge and teacher education. Teachers College Press, New York

Hashweh MZ (2005) Teacher pedagogical constructions: a reconfiguration of pedagogical content knowledge. Teachers Teach Theory Practice 11:273–292

Jang SJ (2006) The effects of incorporating web assisted learning with team teaching in seventh-grade science classes. Int J Sci Educ 28(6):615–632

Jang SJ (2007) A study of the students' construction of science knowledge: talk and writing in a collaborative group. Educ Res 49(1):65–81

Jang SJ (2008a) The effects of integrating technology, observation and writing into a teacher education method course. Comput Educ 50(3):853–865

Jang SJ (2008b) Innovations in science teacher education: effects of integrating technology and team-teaching strategies. Comput Educ 51(2):646–659

Jenkins J, Veal ML (2002) Preservice teachers' PCK development during peer coaching. J Teach Phys Educ 22(1):49–68

Jenkins J, Garn A, Jenkins P (2005) Preservice teacher observations in peer coaching. J Teach Phys Educ 24:2–23

Joyce BR, Showers B (1982) The coaching of teaching. Educ Leadership 40:4–10

Joyce BR, Showers B (1995) Student achievement through staff development: fundamentals of school renewal, 2nd edn. Longman, White Plains

Kim MC, Hannafin MJ, Bryan LA (2007) Technology-enhanced inquiry tools in science education: an emerging pedagogical framework for classroom practice. Sci Educ 91:1010–1030

Koehler MJ, Mishra P, Yahya K (2007) Tracing the development of teacher knowledge in a design seminar: integrating content, pedagogy, and technology. Comput Educ 49:740–762

Lave J, Wenger E (1991) Situated learning: legitimate peripheral participation. Cambridge University Publishers, Cambridge

Lederman NG, Gess-Newsome J, Latz MS (1994) The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. J Res Sci Teach 31:129–146

Levin BB (1999) Analysis of the content and purpose of four different kinds of electronic communications among preservice teachers. J Res Comput Educ 32:139–156

Lewis T (2006) Design and inquiry: bases for an accommodation between science and technology education in the curriculum? J Res Sci Teach 43(3):255–281

Loughran JJ, Mulhall P, Berry A (2004) In search of pedagogical content knowledge in science: developing ways of articulating and documenting professional practice. J Res Sci Teach 41:370–391

Magnusson S, Krajcik J, Borko H (1999) Nature, sources, and development of pedagogical content knowledge. In: Gess-Newsome J, Lederman NG (eds) Examining pedagogical content knowledge. Kluwer Academic, Dordrecht, pp 95–132

McAllister EA, Neubert GA (1995) New teachers helping new teachers: preservice peer coaching. EDINFO Press, Bloomington

McMillan J, Schumacher S (2001) Research in education: a conceptual introduction, 5th edn. Addison Wesley Longman, New York

Mishra P, Koehler MJ (2006) Technological pedagogical content knowledge: a new framework for teacher knowledge. Teachers College Record 108(6):1017–1054

Mulholland J, Wallace J (2005) Growing the tree of teacher knowledge: ten years of learning to teach elementary science. J Res Sci Teach 42(7):767–790

National Research Council (1996) National science education standards. National Academy Press, Washington, DC

Niess ML (2005) Preparing teachers to teach science and mathematics with technology: developing a technology pedagogical content knowledge. Teach Teacher Educ 21(5):509–523

Niess ML, Ronau RN, Shafer KG, Driskell SO, Harper SR, Johnston C, Browning C, Özgün-Koca SA, Kersaint G (2009) Mathematics teacher TPACK standards and development model. Contemp Issues Technol Teacher Educ 9(1):4–24

Pierce D, Hunsaker TW (1996) Professional development for the teacher, of the teacher, and by the teacher. Education 117(1): 101–105

Pope M, Hare D, Howard E (2005) Enhancing technology use in student teaching: a case study. J Technol Teacher Educ 13(4): 573–618

Rosaen CL, Hobson S, Khan G (2003) Making connections: collaborative approaches to preparing today's and tomorrow's teachers to use technology. J Technol Teacher Educ 11(2):281–306

Schaverien L (2003) Teacher education in the generative virtual classroom: developing learning theories through a web-delivered, technology-and-science education context. Int J Sci Educ 25(12):1451–1469

Schmidt DA, Baran E, Thompson AD, Mishra P, Koehler MJ, Shin TS (2009) Technological pedagogical content knowledge (TPACK): the development and validation of an assessment instrument for preservice teachers. J Res Technol Educ 42(2): 123–149

Shotsberger PG (2000) The human touch: synchronous communication in web-based learning. Educ Technol 40(1):53–56

Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res 15:4–14

Shulman LS (1987) Knowledge and teaching: foundations of the new reform. Harvard Educ Rev 57:1–22

Strauss A (1987) Qualitative analysis for social scientists. Cambridge University Press, New York

Thompson AD, Mishra P (2008) Breaking news: TPCK becomes TPACK!. J Comput Teacher Educ 24(2):38

Upitis R, Russell T (1998) Building a teacher education community: combining electronic mail with face-to-face interactions. In: Hamilton ML (ed) Reconceptualizing teaching practice: self-study in teacher education. Falmer Press, London, pp 77–109

Valanides N, Angeli C (2006) Preparing preservice elementary teachers to teach science through computer models. Contemp Issues Technol Teacher Educ Sci 6(1):87–98

Valanides N, Angeli C (2008) Learning and teaching about scientific models with a computer modeling tool. Comput Hum Behav 24:220–233

Van Dijk EM, Kattmann U (2007) A research model for the study of science teachers' PCK and improving teacher education. Teach Teacher Educ 23:885–897

Van Driel JH, Beijaard D, Verloop N (2001) Professional development and reform in science education: the role of teachers' practical knowledge. J Res Sci Teach 38(2):137–158

Van Driel JH, De Jong O, Verloop N (2002) The development of preservice chemistry teachers' PCK. Sci Educ 86:572–590
Vannatta RA, Fordham N (2004) Teacher dispositions as predictors of classroom technology use. J Res Technol Educ 36(3):253–272
Vidmar DJ (2006) Reflective peer coaching: crafting collaborative self-assessment in teaching. Res Strateg 20:135–148
Vygotsky LS (1978) Mind in society. Harvard University Press, Cambridge
Watts-Taffe S, Gwinn CB, Johnson JR, Horn ML (2003) Preparing preservice teachers to integrate technology with the elementary literacy program. Read Teacher 57(2):130–140
Willis EM, Sujo de Montes L (2002) Does requiring a technology course in preservice teacher education affect student teacher's technology use in the classroom? J Comp Teacher Educ 18(3):76–80
Young M (1993) Instructional design for situated learning. Educ Tech Res Dev 41(1):43–58