Longitudinal study of pre-service teachers' development of TPACK in a required educational technology course

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Longitudinal study of pre-service teachers' development of TPACK in a required educational technology course

by

Yi Jin

A dissertation submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education (Curriculum and Instructional Technology)

Program of Study Committee:
Denise A. Schmidt-Crawford, Major Professor
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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University
Ames, Iowa
2017

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DEDICATION

This dissertation is dedicated to my family who unconditionally loves and supports me all throughout my academic journeys. My wonderful grandparents, Li Jiao, Yijing Liu, and Shuzhen Duan, encourage me to pursue my Ph. D. and a career in academia. My parents, Liping Jin and Jian Jiao, always respect my decisions and support them wholeheartedly. My parent-in-laws, Zhiyong Zeng, Rongke Wang, and Yiyong Zeng, are always proud of my academic achievements and send constant encouragements. My husband Zaipeng Zeng and son Aiden Zeng are always my biggest supporters. This dissertation is dedicated to all of them.
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Behind every dissertation, there are a whole group of people who do not sign their names on the dissertation. My team deserves this dissertation more than I do.
This dissertation investigated the impact of prior knowledge, course design, and technology preparation on pre-service teachers' development of technological pedagogical content knowledge (TPACK) in a teacher education program at a large Midwestern land-grant university over a span of nine academic years (Mishra & Koehler, 2006). In this study, 1,246 pre-service teachers participated by responding to both pre- and post-TPACK surveys. A series of statistical analyses were used to analyze the quantitative data collected from these pre- and post-surveys. First, descriptive analyses and a two-step cluster analysis were used to group pre-service teachers into different clusters based on their pre-TPACK scores (low and high). A two-group model was found to be the best fit, and thus, pre-service teachers were grouped into these two clusters. Cluster 1 pre-service teachers reported lower pre-TPACK scores compared to cluster 2 pre-service teachers. Paired-sample t-tests were run to examine whether there were differences in the post-TPACK and TPACK-development scores. The results revealed that cluster 2 pre-service teachers reported higher post-TPACK scores, while cluster 1 pre-service teachers had higher TPACK-development scores. Second, two-way MANOVA tests were used to investigate the impact of prior knowledge, course design, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores. All three variables were found to be statistically significant factors. In particular, a content-specific TPACK course design was more effective than the general course design. Cluster 2 pre-service teachers who reported higher pre-TPACK scores still had higher post-TPACK scores. Conceptual and practical implications are discussed. Future research directions are offered.
CHAPTER 1. GENERAL INTRODUCTION

Introduction

Researchers in the education have been investigating the knowledge teachers need to teach well (Kember, Kwan, & Ledesma, 2001; Lee, Kim, & Chan, 2015; Ramsden, 1991). However, a sound theoretical framework was missing until Shulman (1986, 1987) proposed the pedagogical content knowledge (PCK) framework. He further conceptualized that teachers have several knowledge types - content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational ends (Shulman, 1987). Based on Shulman's work, Grossman (1990) reiterated the interrelationships between teacher knowledge as "four general areas of teacher knowledge … as the cornerstones of the emerging work on professional knowledge for teaching: general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context" (p. 5).

With technology becoming more and more prevalent in everyday life and educational settings, Shulman’s PCK framework alone seems to be inadequate for understanding the knowledge teachers need to teach well in today’s classrooms. Later, several scholars further conceptualized the PCK framework and proposed a framework that included technological knowledge (Angeli & Valanides, 2005; Keating & Evans, 2001; Koehler & Mishra, 2005a, 2005b; Margerum -Leys & Max, 2002; Niess, 2005; Pierson, 1999). In 2006, Mishra and Koehler wrote about the interplay between three independent knowledge domains and emphasized the importance of technological pedagogical content knowledge (TPACK). After over ten years of discussion and dialogue, the TPACK framework has become a common
language that educators use to explain technology integration, as well as a conceptual framework to undergird research and practice.

**Problem Statement**

Technology integration was a priority for many teacher education programs in the late 1990s (Carroll, 2000). Ever since, national and program-wide efforts were put into practice to equip pre-service teachers with the knowledge and skills they needed to meaningfully integrate technology into classrooms (Kleiner, Thomas, & Lewis, 2007). Even after such focused efforts, pre-service teachers were still graduating from teacher education programs feeling unprepared to use and integrate technology (Angeli & Valanides, 2009; Ertmer & Ottenbreit-Leftwich, 2010; Kay, 2006; Sang, Valcke, Van Braak, & Tondeur, 2010; Tondeur, Roblin, van Braak, Fisser & Voogt, 2013). Additional research is still needed, which examines the development of teacher knowledge around technology use and integration. In particular, research studies that investigate pre-service teachers' development of TPACK in and throughout a teacher education program are needed. Although research is emerging in this critical area (Tondeur, van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012; Willermark, 2017), few studies have investigated how variables like prior knowledge and course design impact teacher knowledge and the development of TPACK.

Specifically, the purpose of this dissertation is to examine the impact of prior knowledge, course design, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores after completing a required educational technology course. These pre-service teachers attended a large Midwestern land-grant university and were required to take the educational technology course as part of their preparation program. In the next section, the organization of this dissertation is presented.
Organization of the Dissertation

This dissertation examines whether prior knowledge, course design, and technology preparation impact pre-service teachers' post-TPACK and TPACK-development scores in a required educational technology course. This dissertation follows a non-traditional format, which includes an introduction, three manuscripts prepared for journal publication, and a final chapter that summarizes the findings and recommends further research.

Chapter 1. General Introduction

The first chapter introduces the research topic, presents the problem statement and states the primary purpose of the study. A list of the terms and variables with their definitions is presented in this chapter.

Chapter 2. Literature Review: Technological Pedagogical Content Knowledge (TPACK) - Research and Practice in Teacher Education

In this chapter, an extensive review of the literature on technological pedagogical content knowledge (TPACK) is presented (Mishra & Koehler, 2006). This literature review explicitly focuses on research involving pre-service teachers’ development of TPACK. First, a historical timeline of the development of TPACK framework is presented. Then, further conceptualizations of the framework are shared. This is followed by a section that focuses on pre-service teachers’ development of TPACK. Finally, suggestions for future research and practice are offered.

Chapter 3. Longitudinal Study of Pre-service Teachers Development of TPACK

This chapter presents the findings of a longitudinal study that examines pre-service teachers’ development of technological pedagogical content knowledge (TPACK) after completing a required educational technology course over the span of nine academic years (Mishra & Koehler, 2006). A two-step cluster analysis was used to group pre-service teachers
into distinct groups based on their pre-TPACK scores on the pre-TPACK survey administered prior to starting a required educational technology course (Schmidt et al., 2009). In this model, pre-service teachers were grouped into two clusters that were homogeneous within each cluster according to their pre-TPACK scores from the pre-TPACK survey. In general, pre-service teachers in cluster 1 reported lower pre-TPACK scores, while pre-service teachers in cluster 2 reported higher pre-TPACK scores. Independent-sample t-tests were run to test whether there were differences in the post-TPACK and TPACK-development scores between the two clusters. Post-TPACK scores were derived from the results of the post-TPACK surveys administered at the end of the course. TPACK-development scores were calculated as the differences between the pre-TPACK and post-TPACK scores. Pre-service teachers in cluster 2 still had higher post-TPACK scores. However, cluster 1 pre-service teachers had higher TPACK-development scores. Results from this study demonstrate that pre-service teachers’ prior knowledge is a crucial factor that can impact their development of TPACK in a required educational technology course.

Future directions for research and practical implications are discussed.

**Chapter 4. Impact of Prior Knowledge and Course Design on Pre-service Teachers’ TPACK Development in a Required Educational Technology Course**

This chapter investigates the impact of prior knowledge, course design, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores in a required educational technology course. Three primary variables were used in this study, which were prior knowledge, course design, and technology preparation. Prior knowledge was the variable used to determine the pre-service teachers’ cluster membership. This membership was determined by the two-step cluster analysis conducted in Chapter 3 in which pre-service teachers were grouped into two clusters according to their pre-TPACK scores on the pre-TPACK survey.
completed prior to starting the required educational technology course (Schmidt et al., 2009). Course design is a categorical variable and is determined by which course design pre-service teachers experienced when they took the required educational technology course. There are two designs over the span of nine academic years. The general course design utilized a general approach to teach educational technology, and the other course design focused on a content-specific course design that integrated guidelines and research findings around the TPACK framework. Technology preparation is a variable of time spent on technology integration that represents the independence of observations. Two-way multivariate analysis of variance (MANOVA) was run to examine whether there were statistically significant differences in the post-TPACK and TPACK-development scores based on prior knowledge and course design (Huberty & Olejnik, 2006). In the MANOVA analyses, prior knowledge and course design were used as independent variables and the seven TPACK domains were used as the dependent variables (CK, PK, TK, PCK, TCK, TPK, and TPACK). All three variables were found that affected pre-service teachers’ post-TPACK and TPACK-development scores. Post-TPACK scores were derived from the pre-service teachers’ responses to the same TPACK survey administered at the end of the course. TPACK-development scores were calculated as the differences between the pre-TPACK and post-TPACK scores. In particular, cluster 2 pre-service teachers who reported higher pre-TPACK scores, had higher post-TPACK scores. The content-specific TPACK course design, which taught concepts aligned with the TPACK framework, appears to be more effective for developing pre-service teachers’ TPACK in both clusters. However, although cluster 1 pre-service teachers reported higher TPACK-development scores after taking the course, they still reported lower post-TPACK scores compared to those pre-service teachers in cluster 2. Results of this study provide empirical data on the impact of prior
knowledge, course design, and technology integration on pre-service teachers’ development of TPACK. Future directions for research and practical implications are discussed.

Chapter 5. General Summary

In the final chapter of the dissertation, the findings of Chapters 2, 3, and 4 are summarized. Recommendations for future research are discussed, and suggestions for practice in teacher education programs are shared.

Terms and Definitions

The following is a list of terms with their respective definitions. These definitions are to be used and applied throughout this dissertation.

Constructionism: The originator of constructionism is Seymour Papert, who was a student of Jean Piaget, a key contributor of constructivism. Papert extended Piaget's epistemological theory of constructivism and adapted it into the theory of constructionism. The purpose of this adaptation was to reinvent constructivism to make it compatible with technology integration in classrooms and emphasize the art of learning, such as learning-by-design, problem-based learning, project-based learning, and connected learning. In short, constructionism is a theory of learning where people learn by utilizing their prior knowledge to acquire more knowledge and by making, inventing, doing, and creating in a tangible, sharable, and concrete way (Papert, 1980; Papert & Harel, 1991).

Constructivism: Constructivism is an epistemological theory that proposes the existence of the subjective reality and that knowledge may be constructed by learners either individually or socially (Mills, Bonner, & Francis, 2006). In other words, constructivism occurs when people
constantly construct knowledge inside their mind, and this process is influenced by learner's previous experiences and interactions with people and things (O’Donnell, 2012).

**Content Knowledge (CK):** Content knowledge is the “knowledge about actual subject matter that is to be learned or taught” (Mishra & Koehler, 2006, p. 1026). Teachers must know about the content they are going to teach and how the nature of knowledge is different from various content areas (Schmidt et al., 2009, p. 125).

**Development of TPACK:** Development of TPACK is used mostly to depict the growth of pre-service teachers’ TPACK over a specific amount of time.

**New Literacies:** The rapid development of digital technology has changed the nature of literacy, which produces new ways of creating and understanding texts (Coiro, Knobel, Lankshear, & Leu, 2008; Moje, 2009). As a result, the broad adoption of ICT, the Internet, and increasing access to technology at home, workplace, and school create more approaches to literacy (Mikulecky, 2010; New London Group, 2000; Pew Research Center, 2013a, b). Hence, a dual-level theory of New Literacies emerged from the literature: the uppercase New Literacies is comprised of the multiple perspectives and approaches of the great number of lowercase new literacies research (Leu et al., 2013).

**Pedagogical Knowledge (PK):** Pedagogical knowledge refers to the methods and processes of teaching and includes knowledge in classroom management, assessment, lesson plan development, and student learning (Schmidt et al., 2009, p. 125).
**Pedagogical Content Knowledge (PCK):** Pedagogical content knowledge refers to the content knowledge that deals with the teaching process (Shulman, 1986). Pedagogical content knowledge is different from various content areas, as it blends both content and pedagogy with the goal being to develop better teaching practices in the content areas (Schmidt et al., 2009, p. 125).

**Prior Knowledge:** Prior knowledge is the whole of a person’s knowledge. It is structured, dynamic in nature, available before a particular learning task, and can exist in multiple states (i.e., declarative, procedural, and conditional knowledge). It is also both explicit and tacit in nature and contains conceptual and metacognitive knowledge components (Dochy & Alexander, 1995).

**Technology:** Technology is a broad concept that can mean a lot of different things. For the purpose of this dissertation, technology is referring to digital technology/technologies, that is, the digital tools we use such as computers, laptops, iPods, handhelds, interactive whiteboards, software programs, etc.

**Technology Knowledge (TK):** Technology knowledge refers to the knowledge about various technologies, ranging from low-tech technologies such as pencil to digital technologies such as the Internet, digital video, interactive whiteboards, and software programs (Schmidt et al., 2009, p. 125).
**Technological Content Knowledge (TCK):** Technological content knowledge refers to the knowledge of how technology can create new representations of specific content. It suggests that teachers understand that, by using a specific technology, they can change the way learners practice and understand concepts in a specific content area (Schmidt et al., 2009, p. 125).

**Technological Pedagogical Knowledge (TPK):** Technological pedagogical knowledge refers to the knowledge of how various technologies can be used in teaching, and to understanding that using technology may change the way teachers teach (Schmidt et al., 2009, p. 125).

**Technological Pedagogical Content Knowledge (TPACK):** Technological pedagogical content knowledge refers to the knowledge required by teachers for integrating technology into their teaching in any content area. Teachers have an intuitive understanding of the complex interplay between the three basic components of knowledge (CK, PK, TK) by teaching content using appropriate pedagogical methods and technologies (Schmidt et al., 2009, p. 125).

**Variables**

Chapter 3 and 4 are quantitative research studies that used several shared variables for statistical analysis. These variables are listed here to provide clarification.

**Course Design:** Course design is an independent dichotomous variable, which consists of two categorical independent groups. It is determined by which course design pre-service teachers experienced when they took the required educational technology course. There were two basic designs used in this course over the span of nine academic years. The general course design utilizes an approach that focused specifically on teaching about educational technology, and the
other course design was a content-specific course design that integrated the guidelines and research findings around TPACK framework and really focused on how technology can be used for teaching and learning in specific content areas (e.g., literacy, math, science, social studies).

**Pre-TPACK Score:** Pre-TPACK score is a dependent variable that is measured at the continuous level. It is measured by the scores pre-service teachers reported after completing the pre-TPACK survey. Participants complete the pre-survey before the start of the required educational technology course (Schmidt et al., 2009).

**Post-TPACK Score:** Post-TPACK score is a dependent variable that is measured at the continuous level. It is measured by the scores pre-service teachers reported after completing the post-TPACK survey. Participants complete the post-survey at the completion of the required educational technology course (Schmidt et al., 2009).

**Prior Knowledge:** Prior knowledge is an independent dichotomous variable, which consists of two categorical independent groups. For the purpose of this study, these groups are the cluster membership for which pre-service teachers have been assigned. This membership was determined by a two-step cluster analysis conducted in Chapter 3. Pre-service teachers were grouped into two clusters (High pre-TPACK and Low pre-TPACK) according to their pre-TPACK scores on the pre-TPACK survey before starting the required educational technology course (Schmidt et al., 2009).

**Technology Preparation:** Technology preparation is the variable of time pre-service teachers have spent learning about technology use and integration that is independent of observations.
This dissertation uses a pre- and post-survey design, so there are no relationships between the observations in each group of the independent variable or between the groups themselves.

**TPACK-Development Score:** TPACK-development score is a dependent variable that is measured at the continuous level. It is the difference between the post-TPACK and pre-TPACK scores collected from the pre-TPACK and post-TPACK surveys (Schmidt et al., 2009).

**References**


Carroll, T. G. (2000). If we didn’t have the schools we have today, would we create the schools we have today? *Contemporary Issues in Technology and Teacher Education, 1*(1), 117–140.


CHAPTER 2. LITERATURE REVIEW: TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK) – RESEARCH AND PRACTICE IN TEACHER EDUCATION

Abstract: In this paper, an extensive review of the literature on technological pedagogical content knowledge (TPACK) is conducted, with a particular emphasis on pre-service teachers' development of TPACK (Mishra & Koehler, 2006). First, a historical timeline of the development of the TPACK framework is presented. Then, further conceptualizations of the framework are discussed. A review of literature focused specifically on pre-service teachers' development of TPACK follows. Finally, the strategies and methods used to develop pre-service teachers TPACK are presented. Finally, a summary of the literature review and suggestions for future research and practice are offered.

Keywords: technological pedagogical content knowledge (TPACK), pre-service teachers, history, conceptualization, research, practice
Introduction

The TPACK framework is a conceptual framework proposed by several educational researchers for investigating the knowledge teachers need when they integrate technology into their instruction (e.g., Margerum-Leys & Marx, 2002; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). It displays the complex interplay among teachers’ content, pedagogy, and technology knowledge and is used as an underlying conceptual framework for research in the field of teacher education and educational technology. At the same time, the portrait of the intricately linked knowledge domains guides teachers and teacher educators in everyday practice for designing meaningful technology-infused curriculum.

After the introduction of the TPACK framework, scholarly conversations flourished in the field, as well as the educational research being conducted investigating underlying issues related to the framework. Moreover, studies guided by the TPACK framework are abundant both in the United States and internationally (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). However, questions remain about the research methods being used to provide meaningful results for informing the field. Thus, it is worth looking into the history and current state of the development of this popular conceptual framework. Meanwhile, it is beneficial to synthesize and summarize significant research outcomes and practical strategies, especially in the field of teacher education, which has widely adopted the framework for research and practice.

This paper provides a comprehensive review of the TPACK literature focusing on four specific aspects: 1) the history of the TPACK framework, 2) further conceptualizations of the TPACK framework, 3) TPACK research in teacher education, and 4) TPACK in practice in teacher education programs. Suggestions for future research will be provided at the end.
The History of the TPACK Framework

In 1986, Shulman wrote about the missing paradigm in teacher education and educational research, which disclosed an absence of a focus on the subject matter among educational researchers. He stressed that no educational scholar had investigated how teachers transform their subject matter knowledge into the context of instruction. Moreover, few research studies were conducted on how different formulations of content affect students' learning or misunderstanding. In fact, Shulman cautioned educational researchers that "the consequences of this missing paradigm are serious, both for policy and for research" (Shulman, 1986, p. 6). He argued that there was an apparent need to have a more coherent theoretical framework for understanding the domains and categories of knowledge in teachers' minds. Therefore, to distinguish this distinct knowledge further, Shulman defined three specific types of knowledge needed by teachers: a) subject matter knowledge, b) pedagogical content knowledge, and c) curricular knowledge (Shulman, 1986, p. 9). Despite the importance of teachers possessing the content knowledge, other knowledge domains are crucial for successful teaching as well. Thus, Shulman proposed a framework to help conceptualize the knowledge domains teachers need: 1) content knowledge, 2) general pedagogical knowledge, 3) curriculum knowledge, 4) pedagogical knowledge, 5) knowledge of learners and their characteristics, 6) knowledge of educational contexts, and 7) knowledge of educational ends, purposes, and values, and their philosophical and historical grounds (Shulman, 1987, p. 8). This conceptualization of teachers' knowledge was based "on the belief that there exists a 'knowledge base for teaching' – a codified or codifiable aggregation of knowledge, skill, understanding, and technology, of ethics and disposition, of collective responsibility – as well as a means for representing and communicating it" (Shulman, 1987, p. 4). Moreover, Shulman (1987) highlighted the importance of pedagogical content
knowledge (PCK), which "identifies the distinctive bodies of knowledge for teaching" and blends "the content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8).

Later, Margerum-Leys and Marx (2002) built upon Shulman's work and wrote about the application of the pedagogical content knowledge (PCK) framework to educational technology. Using a quasi-ethnographic interview process, they observed and interviewed three pre-service teachers and three mentor teachers at a middle school. As a result of this study, the researchers proposed a new knowledge set, "the Pedagogical Content Knowledge (PCK) of Educational Technology" (Margerum-Leys & Marx, 2002, p. 446). Instead of adding technology knowledge as a new knowledge domain, they regarded it as a part of the subject matter. Therefore, their depiction of teacher knowledge appears more comprehensive compared to the more limited view that teachers’ educational technology knowledge only includes their awareness of technological applications and affordances. Margerum-Leys and Marx (2002) also reminded teacher educators that teachers needed to have the comprehensive and multi-directional knowledge to be able to use educational technologies effectively in the classrooms. This broader sense of the nature of teachers’ technology knowledge laid a foundation for further conceptualization of teachers’ knowledge domains.

Nearly two decades have passed since Shuman first put forward the PCK framework for scholarly conversations and investigations. Other scholars have explored possible conceptualizations of teachers’ technology knowledge. Pierson (1999) added technology knowledge to the PCK framework and proposed "technological-pedagogical-content knowledge" (p. 224). Specifically, Pierson’s (2001) research study examined three teachers who represented
different mastery levels in teaching and technology integration. She found that teachers’ varying levels of content knowledge and teaching expertise, especially the technology knowledge and pedagogical expertise, were strong indicators of teachers’ ability to integrate technology into classrooms. A new knowledge component, technological knowledge, emerged from her findings. Pierson defined teachers' technological knowledge as something that "would include not only basic technology competency but also an understanding of the unique characteristics of particular types of technologies that would lend themselves to particular aspects of teaching and learning process" (Pierson, 2001, p. 427). In addition, Pierson introduced a new knowledge domain called technological-pedagogical-content knowledge, with the goal to understand the possible relationship between the three knowledge domains (see Figure 1). Pierson argued that teachers must view technological knowledge as an integral part of their knowledge base in order to integrate technology meaningfully into instruction. Pierson’s findings encouraged teachers, teacher educators, researchers, and leaders to examine the intersections of multiple domains of teacher knowledge in order to truly understand technology integration in classrooms.

Figure 1. Relationships among content, pedagogical, and technological knowledge (Pierson, 2001, p. 427).
Keating and Evans (2001) proposed a similar type of teachers' knowledge, something they described as technological pedagogical content knowledge (TPCK). Using grounded theory, Keating and Evans sent out surveys and conducted interviews with eleven pre-service teachers to investigate their perceptions of their personal technology use compared to their attitudes toward using technology as teachers. Three themes emerged from the study - modeling, usage, and pedagogical fit. They identified a gap between pre-service teachers' confidence in personal technology use and their thoughts about technology integration as teachers. Similar to Pierson (2001), Keating and Evans (2001) believed that teacher educators should be responsible for equipping pre-service teachers with the necessary confidence and competence to face these challenges. According to Keating and Evans (2001), TPCK "which extends beyond computer proficiency to understanding the effect technology may have on students' conceptions of subject matter, the inevitable challenges that accompany technology, and the judicious use of technology when new forms of representation are most appropriate" (p. 1671).

Later, other scholars proposed alternative labeling systems for teachers' knowledge domains, which in essence, were congruent with the idea of TPCK. In 2004, Franklin used the term electronic pedagogical content knowledge and skill. Likewise, Irving (2006) suggested the term electronic pedagogical content knowledge (ePCK), specifically designed for science teacher educators. Gunter and Baumbach (2004) suggested that the knowledge needed for effective technology integration was a form of literacy, which consists of computer literacy, information literacy, and integration literacy. The concepts and constructs from these researchers did not actually differ much from Pierson's (1999) conceptualization of TPCK several years earlier.

Several critical articles were published concurrently in 2005, all contributing to establishing a conceptual framework about teachers’ required knowledge domains related to
technology integration (Angeli & Valanides, 2005; Koehler & Mishra, 2005a, 2005b; Niess, 2005). Building on Pierson’s work, Niess (2005) conducted a case study investigating pre-service teachers’ development of technology-enhanced pedagogical content knowledge (TPCK) during a multi-dimensional science and mathematics teacher preparation program. This particular preparation program intently infused technology with teaching and learning throughout the entire program. After analyzing five cases, Niess identified several reasons why pre-service teachers chose not to integrate technology into their instruction. These reasons included such findings as 1) pre-service teachers’ predispositions of the pedagogies used in a particular subject area, 2) time and energy involved in equipping pre-service teachers with the necessary technological skills, and 3) a lack of understanding of the benefits technology brought for enhancing students’ learning in a particular subject area. From these results, Niess highlighted two important aspects to consider for developing pre-service teachers’ TPCK: 1) pre-service teachers’ beliefs about technology integration and 2) the nature of the discipline. Unlike Pierson (2001) who conceptualized TPCK as an end product for teachers, Niess (2005) suggested that the integration of the three knowledge domains could be viewed as a way to cultivate the development of TPCK and a means to effective technology integration in classrooms (Voogt et al., 2013). These findings shed light on the complex interplay among content, pedagogy, and technology knowledge and the challenges teacher educators face when preparing pre-service teachers. These findings suggested that most teachers, pre-service and in-service, require a unique body of knowledge to successfully integrate technology into instruction.

Angeli and Valanides (2005) conducted a study for creating an instructional system design (ISD) model by analyzing data from three consecutive iterations of design experiments. They proposed that the ISD model could be used in a teacher education program to develop pre-
service teachers' information and communication (ICT)-related pedagogical content knowledge (PCK). They postulated that ICT-related PCK included several knowledge domains, such as pedagogical knowledge, subject area knowledge, knowledge of students, knowledge of environmental context, and ICT knowledge. Angeli and Valanides (2005) further defined ICT-related PCK by suggesting five principles: 1) identify topics, 2) identify representations, 3) identify teaching strategies, 4) select ICT tools, and 5) infuse ICT activities.

Built on the significant research in the field (Hughes, 2005; Keating, & Evans, 2001; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys & Marx, 2002, 2004; Niess, 2005; Pierson, 2001; Zhao, 2003), Mishra and Koehler continually worked on their conceptualization of the TPCK framework through a series of publications and conference presentations (e.g., Koehler & Mishra, 2005a, 2005b; Koehler, Mishra, Hershey, & Peruski, 2004; Koehler, Mishra, & Yahya, 2007; Mishra & Koehler, 2003, 2006). As a result of these research efforts, the Technological Pedagogical Content Knowledge (TPCK) framework emerged (Mishra & Koehler, 2006). In particular, except for the three knowledge domains introduced by Shulman (1986) (PK, CK, PCK), four new domains were added and defined: technological knowledge (TK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPCK). TPCK was noted as the interconnection and intersection of content, pedagogy, and technology (see Figure 2) (Mishra & Koehler, 2006, 2009). Although TPCK was not entirely new, Mishra and Koehler were the first to communicate the interrelationship between the three knowledge domains with clarity and used a diagram to help visualize the concept. They also defined each of the seven knowledge domains in the framework.
Mishra and Koehler (2006) emphasized that TPCK was critical to the meaningful and transformative integration of technology in the classrooms. Koehler and colleagues (2007) argued "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" (p. 741). Thus, the TPCK framework does not require a unique pedagogical orientation; instead, it supports various pedagogical approaches to teaching and learning (Harris & Hofer, 2011).

In 2007, the acronym TPCK was changed to TPACK for ease of pronunciation and emphasis on the connotation of being the "Total PACKage" (Thompson & Mishra, 2007, p. 38). Another set of definitions was also developed by Schmidt and colleagues (2009). In later works, TPACK was summarized "as situated, complex, multifaceted, integrative and/or transformative" (Chai, Koh, & Tsai, 2013, p. 32). Overall, the conceptualization of the TPACK framework offers both researchers and educators a common language for more scholarly conversations and
understanding about the topic of technology integration. Other scholars have since continued to further conceptualize the TPACK framework.

**Further Conceptualizations of the TPACK Framework**

Several researchers in the education field have used the TPACK framework to illuminate the domains and categories of the knowledge teachers need for designing meaningful technology-infused instruction (Hughes, 2005; Keating, & Evans, 2001; Lundeberg et al., 2003; Margerum-Leys & Marx, 2002, 2004; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001; Zhao, 2003). Researchers continue to work on re-conceptualizing the TPACK framework to deepen the understanding of teachers' knowledge to address the complexities of technology integration in various contexts (e.g., Benton-Borghi, 2013, 2015; Di Blas & Paolini, 2014, 2016, 2017; Porras-Hernandez & Salinas-Amescua, 2013).

**Defining the TPACK Domains**

A number of researchers have provided definitions for each of the seven knowledge domains in the TPACK framework (Archambault & Barnett, 2010; Cox, 2008; Cox & Graham, 2009; Lee & Tsai, 2010; Schmidt et al., 2009). Graham (2011) noted three specific challenges in theorizing the TPACK framework. First, the TPACK framework was built on Shulman’s PCK framework, which lacked theoretical clarity. Researchers had difficulty in producing precise definitions for the PCK knowledge domains, so it is challenging to measure PCK. Second, it was challenging to find a balance between parsimony and complexity. Comprehensiveness is the inclusion of all the factors that are relevant to the phenomena, while parsimony, on the contrary, is the simplification, which only includes the most valuable factors in understanding the phenomena. Third, scholars in the field did not agree upon a set of precise definitions for the frameworks’ seven knowledge domains.
A prerequisite for theorizing the TPACK framework is to test the existence of the seven constructs. Several researchers used exploratory factor analysis (EFA) to test the existence of the seven knowledge domains quantitatively (Archambault & Barnett, 2010; Archambault & Crippen, 2009; Lee & Tsai, 2010; Lux, 2010; Schmidt et al., 2009). According to Graham (2011), researchers discovered that the TPACK framework was “fuzzy” and needed further conceptualization (Angeli & Valanides, 2009; Archambault & Crippen, 2009; Graham, 2011; Jimoyiannis, 2010; Niess, 2011).

Cox (2008) conducted a conceptual analysis of the TPACK framework with the purpose of clarifying the seven constructs. Cox found 89 different definitions of TPACK, as well as ten definitions for TPK and thirteen for TCK. As a result of her research, Cox provided a list of definitions for each knowledge domain in the hope of providing a foundation for future studies. Cox further conceptualized the TPACK framework and provided a model that illustrated the constructs (see Figure 3). She argued that when technologies became transparent and ubiquitous, TPACK would transform into PCK. For example, when teachers use transparent technologies such as the pencil, the whiteboard, the book, they are tapping into their PCK repertoire. Cox defined emerging technologies as new digital technologies, which were being introduced into a learning environment. Cox (2008) argued that when teachers were using emerging technologies, they were using their TK, TPK, TCK, and TPACK. Later, Cox and Graham (2009) stressed the importance of clarifying the definitions of each TPACK domain and focusing on the independence of each knowledge domain to assist the facilitation of studying TPACK in practice. Chai, Koh, and Tsai (2013) agreed with this view and published another set of succinct definitions for each TPACK domain, which included explicit examples for each (p. 33).
The integrative view of TPACK being a knowledge domain built upon the interactions of other domains, quickly gained popularity. Many research studies were conducted with several reported outcomes (Willermark, 2017), but on the contrary, Mishra and Koehler (2006) proposed a transformative understanding of TPACK (Graham, 2011). Another point of view of TPACK surfaced and distinguished itself by having an alternative research focus, the transformative nature of TPACK. Angeli and Valanides sought to provide a more precise explanation of TPACK by reporting results from several studies (i.e., Angeli & Valanides, 2005, 2009).

Angeli and Valanides (2009) concluded that TPCK was a unique body of knowledge gained from the interactions of its constituent components, which was derived from their findings that the growth in individual knowledge domains did not guarantee TPCK development (Angeli, 2005; Angeli & Valanides, 2005, 2009; Valanides & Angeli, 2006, 2008a, 2008b). This transformative point of view places the main focus on TPCK itself instead of on the individual knowledge domains. Angeli and Valanides (2009) further conceptualized the ICT-TPCK model.
(see Figure 4) to include five different knowledge bases: 1) subject matter knowledge, 2) pedagogical knowledge, 3) knowledge of learners, 4) knowledge of context, and 5) ICT knowledge.

![Figure 4. ICT-TPCK framework (Angeli & Valanides, 2009, p. 159).](image)

Thus far, three perspectives of TPACK have emerged over a ten-year span (Voogt et al., 2013). Niess (2005) and Cox and Graham (2009) regarded the TPACK framework as an extension of Shulman's (1986, 1987) PCK framework. Angeli and Valanides (2009) adopted a transformative view that TPCK was a unique and distinct body of knowledge. Finally, the most popular point of view is that of Mishra and Koehler's (2006, 2009), which suggests that TPACK is the interplay between the three knowledge domains and the intersections that exist within a particular context.

“Context” within the TPACK Framework

To unpack context in the TPACK framework, Mishra and Koehler (2006) argued “productive technology integration in teaching needs to consider all three issues not in isolation, but rather within the complex relationships in the system defined by the three key elements” (p.
Mishra and Koehler requested teachers and teacher educators to carefully consider the contextual knowledge needed to develop this nuanced understanding. Similarly, Cox (2008) believed that "the effect of context is that TP[A]CK is unique, temporary, situated, idiosyncratic, adaptive, and specific and will be different for each teacher in each situation" (p. 47).

As more researchers situate their empirical research within the TPACK framework, it became evident that the outer dotted circle, “context,” was not clearly defined (Rosenberg & Koehler, 2015). Early on, Koehler and Mishra (2005a) referred to the existing dotted circle as "context bound" (p. 1032), which was a situated form of knowledge. They posit that context included subject matter, grade level, student background, and the types of available technologies. In 2007, Kelly argued that teachers’ success in improving students’ learning outcomes depended on how well they adapted to the unique context. Kelly (2008a) continued the conversation of further defining “context” by adding the physical elements, such as the design of the learning environment and the characteristics of the school into the context. As a result, “context” was placed around the TPACK Venn diagram to highlight its importance (Koehler & Mishra, 2008, see Figure 2).

Doering, Veletsianos, Scharber, and Miller (2009) focused on developing teachers' TPACK within a specific subject area, geography. They called their extension of the TPACK framework, G-TPCK. Doering et al. (2009) stated that TPACK was a dynamic concept and the context was crucial in its role of impacting both teacher knowledge and practice. They stressed that TPACK "should be seen as an evolving and multi-faceted entity rather than a static representation of teacher's knowledge" (Doering et al., 2009, p. 336). To illustrate their findings, they used three circles of different sizes to show that at times teachers’ CK was larger than PK and/or TK. They also added a shaded shape around their variation of the TPACK Venn diagram.
to represent context knowledge and argued that context "influenced the way teachers' knowledge is applied and used in the classroom" (Doering et al., 2009, p. 336).

Further conceptualization of “context” continued (e.g., Chai et al., 2013; Porras-Hernandez & Salinas-Amescua, 2013; Rosenberg & Koehler, 2015). Chai et al. (2013) redesigned the framework adding the Technological Learning Content Knowledge (TLCK) (see Figure 5). They conceptualized “context” from both teachers' and students' perspectives and identified four interdependent contextual factors: 1) intrapersonal dimension, 2) interpersonal dimension, 3) cultural/institutional factors, and 4) physical/technological provision in schools.

![Figure 5. TPACK and TLCK frameworks (Chai et al., 2013, p. 45).](image)

Porras-Hernandez and Salinas-Amescua (2013) investigated “context” using both Angeli and Valanides' ICT-related PCK framework (2005) and Mishra and Koehler's TPACK framework (2006). They proposed that “context” consist of: 1) student characteristics, 2) classroom and institutional conditions for learning, 3) situated teaching activities, and 4)
teacher’s epistemological beliefs. They argued that one should view “context” in two dimensions: scope (macro-, meso-, and micro-level context) and actor (students' and teachers' inner and external context). The macro context includes the social, political, technological, and economic conditions. The meso level is composed of schools, principals, and superintendents. The micro level consists of in-class conditions for learning, which encompass the available resources for learning activities, norms, policies, expectations, beliefs, preferences, and goals.

In a systematic review of research conducted by Rosenberg and Koehler (2015), the authors drew from the conceptual work developed by Porras-Hernandez and Salinas-Amescua (2013), and advanced it by adding the actors, teachers, and students into the original TPACK framework. Rosenberg and Koehler found that only 36% \((n = 70)\) of 193 published empirical TPACK articles referred to the “context” by highlighting the contextual factors involving teachers. However, those same 70 studies made few considerations of the contextual factors related to students and society.

Although “context” is critical in most educational settings, especially when using technology, it is often missing or not adequately described in a lot of TPACK research. Moreover, “context” is not unified systematically or comprehensively, which results in widely different representations in the existing literature. Therefore, it is essential that educational researchers address the conceptual challenges of understanding the context around TPACK, as well as how and why context impacts teachers' development of TPACK. Meanwhile, more empirical studies are needed to assess practice and provide evidence for conceptualizing the characteristics of the “context” related to TPACK.
Extensions of the TPACK Framework

Since its inception, researchers have been revising and expanding upon the work of the original TPACK framework (Mishra & Koehler, 2006) by integrating it with other existing theories and frameworks (e.g., Benton-Borghi, 2015; Lee & Tsai, 2010; Saad, Barbar, & Abourjeili, 2013; Yeh, Hsu, Wu, Hwang, & Lin, 2014). Lee and Tsai (2010) focused on grounding the TPACK framework in the context of teachers integrating Web technology into their pedagogical practice. They posited that teachers needed TPCK-Web to teach with the web, as it was a form of teacher knowledge specific to Web-based instruction. They substituted TK with Web Knowledge, thus making three new teacher knowledge domains, 1) Web-Pedagogical Knowledge, 2) Web-Content Knowledge, and 3) Web-Pedagogical-Content Knowledge. Lee and Tsai (2010) claimed that Web knowledge "encompasses the knowledge about the general use of the Web such as the use of web-related tools, as well as knowledge about its advanced use relative to Web-based communication or Web-based interaction" (p. 4).

Others sought to integrate other disciplinary knowledge (e.g., literacy, STEM, educational psychology, sociology) into the TPACK framework. For example, Saad and colleagues (2013) created a TPACK-XL framework that was built upon the original TPACK framework but added the knowledge of educational psychology and educational sociology (see Figure 6). The TPACK-XL framework stressed the broad interdisciplinary knowledge that pre-service teachers needed. The emerging TPCLX Interdisciplinary Knowledge highlighted both "the general and particular, the global and local, the universal and situated, the international and national knowledge of the basic five disciplines and their interrelation that enables pre-service teachers to develop thoughtful content-specific, situated teaching practices" (Saad et al., 2013, pp. 51–52).
Yeh et al. (2014) conducted a Delphi study to investigate what types of knowledge represent experienced teachers' knowledge. They offered a TPACK-Practical model, which was composed of eight knowledge domains in five pedagogical areas (see Figure 7). This alternative TPACK framework called researchers to examine the differences in the development and enactment of TPACK between novice and experienced teachers and had direct implications for teacher educators on how to better prepare teachers’ TPACK.

Figure 6. TPACK-XL theoretical framework model (Saad, Barbar, & Abourjeili, 2013, p. 50).

Figure 7. TPACK-Practical model (Yeh et al., 2013, p. 714).
Benton-Borghi (2015) aligned the Universal Design for Learning (UDL) framework with TPACK to create a framework called the UDL-Infused TPACK Practitioners' Model. Benton-Borghi argued that as more instructional materials became digital, teachers must understand the principles of Universal Design Learning (UDL) and the affordances of different technology tools to provide equitable learning opportunities for diverse and exceptional students. Furthermore, she suggested that every teacher should integrate UDL into the TPACK framework so that general and special education teachers alike could work together in designing meaningful technology-infused lessons for diverse and exceptional students (Benton-Borghi, 2015). The UDL-Infused TPACK Model would "add clarity to the conceptual framework and construct validity of the components" for the TPACK framework (Benton-Borghi, 2015, p. 295). Three UDL principles should be considered at all levels when using the TPACK framework: 1) how to represent the content (Input), 2) how to engage the students (Output), and 3) how to assess student understanding of content from multiple perspectives (Engagement).

**Conceptualizations of the TPACK Enactment**

Numerous studies have reported findings on pre-service teachers' development of TPACK (Willermark, 2017). Very few have investigated the process of developing pre-service teachers' TPACK using longitudinal design, as well as the enactment of pre-service and in-service teachers' TPACK (Kessler & Rosenberg, 2017; Mouza 2016; Phillips, 2016; Phillips, Koehler, Rosenberg, & Zunica, 2017). A few scholars focused their research efforts on examining the enactment of TPACK in actual teaching and learning environments. For example, Di Blas, Paolini, Sawaya, and Mishra (2014) argued that in practice, TPACK might be distributed and shared by several teachers. Phillips (2016) argued the process of identity development and practice impact TPACK enactment in actual professional settings. Moreover,
Kessler and Rosenberg (2017) proposed a model of TPACK enactment, called Leveraging TPACK during Mental Engineering of Instruction, to assist in conceptualizing and measuring the cognitive process during instruction.

Di Blas et al. (2014) challenged the traditional conception that individual teachers possessed TPACK in their heads and suggested that a new concept, distributed TPACK, might be more realistic in specific contexts. They postulated that TPACK could be distributed across social tools (teachers, technologies, students) and cognitive tools (websites, lesson plans, books, software, etc.). This advancement of the framework had both theoretical and practical implications. Theoretically, if TPACK could be distributed across social and cognitive tools, the role of the teacher was no longer the sage of knowledge. Instead, teachers became the conductors who navigate various resources and instruments to facilitate a meaningful learning experience for students. In practice, TPACK became "dynamic and the roles played by individuals are not predefined but rather negotiated and discovered" (Di Blas et al., 2014, p. 2469). This perspective was shared by several scholars in the field (e.g., Jones, Heffernan, & Albion, 2015; Phillips, 2013, 2014).

Di Blas and Paolini (2016) continued to conceptualize distributed TPACK. Using a case study approach, they found evidence that TPACK was both distributed and dynamic, which was later confirmed by replication (Di Blas & Paolini, 2017). Di Blas and Paolini emphasized the dynamic nature of TPACK. After carefully examining the three independent TPACK domains, they reported that TK and CK were both distributed and dynamic. However, PK was only dynamic among actors. In later work (Di Blas & Paolini, 2017), they named the distributed and dynamic TPACK as DD-TPACK (Di Blas, & Paolini, 2017).
Phillips (2016) adopted a Community of Practice (CoP, Wenger, 1998) perspective to investigate a case study involving an in-service teacher and TPACK. Phillips found that TPACK enactment had a strong connection with identity, practice, and knowledge, which implied that TPACK enactment was a socially mediated phenomenon existing in a complex system of participation and interaction. He argued that "understanding context as both a location for the exhibition of knowledge as well as a series of socially mediated process that shape enactment address Hager's (2005) criticism of workplace learning theories that rely on single-factor or universally applicable explanations" (Phillips, 2016, p. 565). Phillips concluded that TPACK was both knowledge and knowing. Moreover, TPACK enactment was a continual process that was influenced by the CoP framework, especially the "processes of identity development (imagination, engagement, alignment, and trajectory) and process of practice (mutual engagement, shared repertoire, joint enterprise and reification)" (Phillips, 2016, p. 567). Thus, context could be considered as a series of socially mediated practices categorized by identity and practice in which teachers exhibited their enactment of TPACK in the workplace. TPACK is also ever-changing, which tied teachers' past participation in a CoP with their current competence and expected future competence.

Despite the approach of investigating the contextual knowledge for understanding teachers' TPACK enactment, several scholars utilized a cognitive approach and reported their findings around the cognitive processes of TPACK enactment (Kessler & Rosenberg, 2017; Krauskopf, Zahn, & Hesse, 2015). Krauskopf et al. (2015) unpacked teachers' cognitive processes as a series of cognitive procedures, mental models, cognitive transformation, and meta-conceptual awareness. These researchers stated that teachers transformed their knowledge in the foundational knowledge domains (TK, PK, CK) and then into knowledge in the
overlapping knowledge domains (PCK, TPK, TCK). This intentional cognitive transformation was called the construction of mental models. For this step, a mere combination of the factual prior knowledge was not enough. Elements of prior knowledge that pertained to the lesson plan or instructional tasks "need to be represented together with their interrelations in such a way that they can be mentally manipulated, so that inferences can be made" (Krauskopf et al., p. 45). Teachers would then experience a second level of transformation, the knowledge representation of TPCK as meta-conceptual awareness, defined as an elaborate, scientific understanding of "what was necessary for mastering the domain of teaching with emerging technology" (Krauskopf et al., p. 50). Overall, their work extends the TPACK framework by arguing it is coherent and that it would be beneficial to view TPCK as a construct.

Kessler and Rosenberg (2017) proposed a new model for the enactment of TPACK, called Leveraging TPACK during Mental Engineering of Instruction (see Figure 8). This conceptual framework appears promising for understanding how teachers enact TPACK in a real learning situation. Built upon the work of Krauskopf, Zahn, and Hesse (2015), Kessler and Rosenberg argued that except for the contextual factors, there was another step in the mental process of planning and enacting instruction - the Mental Engineering of Instruction. The Mental Engineering of Instruction represents and binds a teachers' mental work and suggests "that it acts as a lens or filter in which the knowledge must be activated through in order to reach a new meta-conceptual awareness space" (Kessler & Rosenberg, 2017, p. 2). Thus, Mental Engineering of Instruction was a teacher's mental space in which he or she could activate different knowledge domains in consideration of personal and professional beliefs, as well as contextual factors to engineer lesson plan ideas.
TPACK Research in Teacher Education

Mishra and Koehler (2006) reconsidered Shulman's (1986) delineation of teachers' professional knowledge and built on the notion of pedagogical content knowledge (PCK) to develop the TPACK framework. Ever since, the TPACK framework has been used by teacher educators to rethink how to prepare pre-service teachers for technology integration (Voogt et al., 2013). It has also been used as a common language to understand and measure pre-service teachers' development of TPACK (Abbitt, 2011).

Before synthesizing the research in this area, it is worth mentioning at the various formats teacher education programs utilize for preparing pre-service teachers to integrate technology. Most teacher education programs have one stand-alone educational technology course for developing pre-service teachers' TPACK, while other programs integrate technology throughout their methodology courses and field experiences. Despite the approach used by the individual teacher education programs, researchers have conducted a significant number of studies on pre-
service teachers' development of TPACK using a variety of research methodologies (Archambault, 2016; Chai, Koh, & Tsai, 2016).

**Research on Pre-service Teachers' Development of TPACK**

Studies centered on examining pre-service teachers’ development of TPACK are numerous (Abbitt, 2011; Tondeur, van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012). Many research studies have been conducted to investigate the interplay between the knowledge subscales (e.g., Kereluik, Casperson, & Akcaoglu, 2010), to define the overlapping knowledge (e.g., Cox, 2008; Cox & Graham, 2009; Graham, 2011), to study pre-service teachers' self-reported TPACK (e.g., Albion, Jamieson-Proctor, & Finger, 2010; Sahin, 2011), to think about the order of knowledge subscales teachers should develop (e.g., Hofer & Grandgenett, 2012), and to investigate different ways TPACK can be distributed among teachers (e.g., Di Blas et al., 2014). Specifically, researchers have been devoting much attention to investigating how pre-service teachers develop their TPACK during their teacher education programs (e.g., Finger, Jamieson-Proctor, & Albion, 2010; Jang & Chen, 2010; Kereluik et al., 2010; Ward & Overall, 2010). For this purpose, it is worth investigating what methods were used and whether they are valid, reliable, and practical measurements of TPACK (Kelly, 2010; Koehler, Shin, & Mishra, 2012). Koehler et al. (2012) categorized the research methodologies used to examine TPACK into five areas: 1) Self-reported measures (i.e., Likert scale), 2) open-ended questionnaires (i.e., written responses from open-ended questions), 3) performance assessments (i.e., rubric, performance task, artifact, lesson plan, reflection paper, and content analysis), 4) interviews, and 5) observations (i.e., field notes, video recordings of a lesson) (Gall, Gall, & Borg, 2007). In the following sections, results from the research studies in these five areas are synthesized.
Qualitative methods.

Qualitative research methodologies provide education researchers valuable opportunities to investigate teachers' development of TPACK with special considerations to various contextual factors. Several qualitative methods are commonly used by researchers, such as performance-based assessment (e.g., Brantley-Dias, Kinuthia, Shoffner, de Castro, & Rigole, 2007; Harris, Grandgenett, & Hofer, 2010; Harris & Hofer, 2011; Kinuthia, Brantley-Dias, & Clarke, 2010; Koehler et al., 2012; Mouza & Karchmer-Klein, 2013), open-ended questionnaires (e.g., Calik, 2013; Mouza, Karchmer-Klein, Nandakumar, Ozden, & Hu, 2014; So & Kim, 2009; Tokmak, Yelken, & Konokman, 2013; Valtonen et al., 2011), interviews (e.g., Jaipal & Figg, 2010; Kinuthia et al., 2010; Maeng, Mulvey, Smetana, & Bell, 2013; Ozgun-Koca, 2009), and observations (e.g., Crawford, Tai, Wang, & Jin, 2016; Harris et al., 2010; Hofer, Grandgenett, Harris, & Swan, 2011; Suharwoto, 2006).

Research results from qualitative studies demonstrate the effectiveness of the TPACK framework for thinking about teachers' meaningful technology integration (Harris et al., 2010; Hofer & Harris, 2010; Koehler & Mishra, 2009). Using the TPACK framework, all educators have a common language for thinking about the preparation required for technology integration (Graham, Borup, & Smith, 2012). Similarly, pre-service teachers can also use this framework to guide their learning, planning, and classroom practice (Groth, Spickler, Bergner, & Bardzell, 2009; Mouza & Karchmer-Klein, 2013).

Sufficient scaffolding and modeling by teacher educators which facilitates technology integration in content-specific situations are found to be critical factors for pre-service teachers' development of TPACK (Calik, 2013; Kennedy-Clark, 2011). Pre-service teachers reported that they feel motivated to integrate technology into their instruction after they observed teachers
successfully integrating the technology in the classroom (Haydn & Barton, 2007). However, in reality, it might be challenging for teacher education programs to provide every pre-service teacher with the opportunity to observe such a teacher (Tearle & Golder, 2008). One possible approach to addressing this issue is to systematically integrate technology within all the courses in a teacher education program to maximize pre-service teachers' exposure to effective modeling on content area specific technology integration (Kirschner & Selinger, 2003; Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010; Tondeur et al., 2012). Additionally, pre-service teachers need to experience the instructional design, development, and delivery processes of integrating technology into a particular content area. Every pre-service teacher should experience technology use and modeling examples in their teacher education programs and cooperating schools - in the courses, field experiences, and student teaching settings (Angeli & Valanides, 2009; Enochson & Rizza, 2009; Niess, 2005).

In 2012, Tondeur et al. conducted a systematic review of the qualitative research on the topic of pre-service teachers' technology integration using a meta-ethnographic approach. They analyzed nineteen articles from eight different journals and six different countries. As a result of this analysis, they reported seven key themes associated with pre-service teachers' technology use and integration. These themes were: 1) aligning theory and practice, 2) using teacher educators as role models, 3) reflecting on attitudes about the role of technology in education, 4) learning technology by design, 5) collaborating with peers, 6) scaffolding authentic technology experiences, and 7) moving from traditional assessment to continuous feedback (Tondeur et al., 2012). In addition, they summarized another five themes related to technology integration and innovation at the institutional level: 1) technology planning and leadership, 2) cooperation within and between institutions, 3) staff development, 4) access to resources, and 5) systematic and
systemic change efforts (Tondeur et al., 2012). These authors stressed the importance of focusing on the relationships among the key themes and viewing them as a system (see Figure 9). Tondeur et al. also suggested that teacher educators attend to all the key themes with careful consideration when preparing pre-service teachers' to use and integrate technology into classrooms.

Figure 9. SQD Model (Tondeur et al., 2012, p. 141).

Although qualitative studies yield productive results, there is still a significant need for using multiple data sources for data triangulation. Researchers must continue to define and operationalize the components of the TPACK framework, develop more validated content-specific qualitative instruments, and collect artifacts with enough specificity (Archambault, 2016).

**Quantitative methods.**

Self-reported measures are the most widely used quantitative research methodology found in the TPACK research, which usually asks pre-service teachers to rate themselves on each knowledge subscale using a survey or questionnaire. Koehler and Mishra (2005) first
designed a survey to measure master students' development of TPACK. Following a survey validation process, Schmidt et al. (2009) designed a survey, specifically for pre-service teachers majoring in elementary or early childhood education. Schmidt et al. used the survey in a pre-post design study and reported that pre-service teachers self-reported gains in all seven knowledge domains after taking a required educational technology course. In particular, they found large growth in the TK, TCK, and TPACK domains. The same survey was applied to at least 26 journal articles (Willermark, 2017), and was adapted by a significant number of scholars to examine the development of TPACK of different populations (e.g., Chai, Koh, & Tsai, 2010; Kaya & Dag, 2013; Koh, Chai, & Tsai, 2010).

Sahin (2011) and Jamieson-Proctor et al. (2013) developed TPACK surveys following a strict survey validation process. These surveys include reliable measures demonstrated by relatively high internal consistency scores. Other research instruments were developed to examine pre-service teachers' self-reported TPACK with a particular focus (e.g., learning with ICTs: measuring ICT use in the curriculum, Jamieson-Proctor et al., 2007; TPCK-W survey, Lee & Tsai, 2010; TPACK for online learning survey, Archambault & Barnett, 2010; PT-TPACK survey, Lux, Bangert, & Whittier, 2011; Krauskopf, Zahn, & Hesse, 2012; the interactive whiteboard (IWB) TPACK survey, Jang & Tsai, 2012; game-based TPACK survey, Hsu, Liang, Chai, & Tsai, 2013; digital videos for teaching and learning survey, Blonder et al., 2013; Web Pedagogical Content Knowledge survey, Kavanoz, Yuksel, & Ozcan, 2015; TPACK-P survey, Jen, Yeh, Hsu, Wu, & Chen, 2016). Content-specific TPACK surveys were also developed (e.g., Bilici, Yamak, Kavak, & Guzey, 2013; Chai et al., 2013; Graham et al., 2009; Jang & Tsai, 2013; Lin, Tsai, Chai, & Lee, 2013), as well as pedagogy-specific TPACK surveys (e.g., Chai, Koh, & Tsai, 2011; Chai, Koh, Tsai, & Tan, 2011; Koh, Chai, & Tsai, 2013; Chai, Ng, Lee,
Hong, & Koh, 2013). Cavanagh and Koehler (2013) stated that several researchers had successfully accumulated content, substantive, structural, and generalizability evidence, and addressed the criticism that the seven TPACK factors lacked construct validation (Brantley-Dias & Ertmer, 2013) over the decade of TPACK survey research (Chai et al., 2016). Overall, the creation and validation of these surveys provided the field with a significant number of instruments that measure pre-service teachers’ development of TPACK in different contexts.

Performance-based measures, especially rubrics, are another popular quantitative measurement commonly used in TPACK research. In 2005, Angeli and Valanides developed a rating scale to assess pre-service teachers' TPCK lesson plans. Later, Harris et al. (2010) validated a rubric for assessing pre-service teachers' TPACK by grading their lesson plans. These lesson plans were created for various content areas and grade levels. The raters of the study graded these lesson plans from one to four based on four categories, 1) curriculum goals and technologies, 2) instructional strategies and technologies, 3) technology selections and 4) fit. Thus, like Schmidt et al.’s (2009) survey, this rubric has been used widely by researchers in the field (Hofer & Grandgenett, 2012; Kafyulilo, Fisser, Pieters, & Voogt, 2015; Kopcha, Ottenbreit-Leftwich, Jung, & Baser, 2014).

Additional researchers have used performance-based measures in their work. Kohen and Kramarski (2012) developed an instrument to test teachers' integration of self-regulated learning (SRL) when they integrated technology into a TPACK lesson. Koh (2013) developed another validated rubric to analyze pre-service teachers' lesson activities. Results from these studies indicate that rubrics are valuable measures to use when examining pre-service teachers’ performance or actual ability to integrate technology into lesson plans.
Research results from quantitative studies showed again that dynamic modeling from teacher educators is a strong predictor of pre-service teachers' development of TPACK. Appropriate and sufficient modeling by teacher educators helps pre-service teachers develop TK, TCK, TPK, and TPACK (Horzuma, 2013; Tokmak, Yelken, & Konokman, 2013; Young, Young, & Hamilton, 2013). In contrast, the lack of modeling or poor modeling negatively impacts pre-service teachers' development of TPACK (Semiz & Ince, 2012). These results stress the necessity of providing adequate and high-quality technology integration modeling to pre-service teachers throughout their teacher education program experiences.

Pre-service teachers' teaching experiences are also another robust predictor for developing the integrated knowledge domains of TPACK (Chai et al., 2013; Pamuk, 2012). In particular, pre-service teachers who have more teaching experiences developed more PCK and TPACK during their preparation, while pre-service teachers with fewer experiences developed relatively less TPACK (Kaya & Dag, 2013; Rohaan, Taconis, & Jochems, 2012). These results shed light on the importance of providing pre-service teachers opportunities for teaching in the field early on and frequently throughout their preparation program.

Finally, there is a strong correlation between TK and the development of TPACK (Chuang & Ho, 2011; Kabakci Yurdakul & Çoklar, 2014; Meriç, 2014). This finding demonstrated that although there was a high need for teacher educators to move away from the technocentric ways of preparing pre-service teachers, it is still important that pre-service teachers gain more technology knowledge by learning about and using technology in multiple courses, field experiences, and student teaching.
TPACK in Practice in Teacher Education Programs

In this section, a review of the literature on the topic of TPACK in practice in teacher education programs is offered. First, the conceptual foundations for preparing pre-service teachers to integrate technology are introduced. Then, the various formats used in different teacher education programs, as well as the strategies used to prepare pre-service teachers are discussed. Third, the planning cycles for designing TPACK lessons and the rubrics developed to evaluate pre-service teachers' TPACK lesson plans are presented.

Pre-service Teachers’ Development of TPACK

Building on Grossman's (1989, 1990) work, Niess (2005) adapted four central components of the PCK framework to help conceptualize the development of TPCK in a science and mathematics teacher education context. These components were:

1) An overarching conception of what it means to teach a particular subject integrating technology in the learning;

2) Knowledge of instructional strategies and representations for teaching particular topics with technology;

3) Knowledge of students' understandings, thinking, and learning with technology in a particular subject;

4) Knowledge of curriculum and curriculum materials that integrate technology with learning and curriculum materials that integrate technology with learning in the subject area (Borko & Putnam, 1996, p. 690). (p. 511)

This set of TPACK components were created for science and mathematics teachers. This does raise a critical question about whether TPACK knowledge is domain-general or domain-specific
(Angeli et al., 2016). Future researchers should consider comparing and contrasting the knowledge teachers need for teaching various content areas.

In 2007, Niess, Lee, and Sadri adapted Rogers' (1995) model of the innovation-decision process to conceptualize different phases teachers go through to develop TPACK (see Figure 10). This model elaborated on the developmental progression in TPACK, which is the result of over four-year observations of in-service teachers' professional development. They argue that this process informs how teacher educators could design curricula in a teacher education program.

These four central components and the process model lay a solid foundation for teacher educators to think about how to prepare pre-service teachers for technology integration. A number of researchers have used the components and this model for their conceptual foundation in research and practice (e.g., Buss, Wetzel, Foulger, & Lindsey, 2015; Foulger, Buss, Wetzel, & Lindsey, 2012, 2015; Özgün-Koca, Meagher, & Edwards, 2011; Wetzel, Buss, Foulger, & Lindsey, 2014).

Figure 10. A visual description of teacher levels of TPACK (Niess et al., 2009, p. 10).
Approaches for Technology Integration Preparation in Teacher Education

Traditionally, teacher preparation programs prepare pre-service teachers for their technology integration in a standalone educational technology course (e.g., Beck & Wynn, 1998; Brubacher & Wilson, 2009; Chai et al. 2010; Gronseth et al., 2010; Polly, Mims, Shepherds, & Inan, 2010; Wetzel, Foulger, & Williams, 2008). It is the expectation of these programs that pre-service teachers should be able to infuse technology into their curricula after taking this standalone technology course (Brush et al., 2002). Many research studies were conducted to investigate pre-service teachers' development of TPACK after taking this kind of standalone technology course (e.g., Chai et al., 2011; Koh & Divaharan, 2011; Schmidt et al., 2009). In a study conducted by Schmidt et al. (2009), the researchers found that pre-service teachers developed all seven TPACK subscales after taking a standalone technology course, especially in TK, TCK, and TPACK. Other researchers also reported that such a course had positive impacts for developing pre-service teachers' confidence and technology skills (Bai & Ertmer, 2008; Foulger et al., 2012). Chai et al. (2011) reported that the relationship between pre-service teachers’ PK and TPACK was insignificant, while the relationship between CK and TPACK becomes significant after completing such a course. It became apparent from these results that for pre-service teachers to fully develop their TPACK, a standalone educational technology course is not enough (Kay, 2006; Polly et al., 2010). More preparation is needed, especially content-specific preparation for technology integration (Harris & Hofer, 2009a; Niess, 2009).

Researchers agree that limited pedagogical knowledge inhibits pre-service teachers' technology integration, and in turn, their development of TPACK (Pamuk, 2012). Some programs have been successful at integrating technology into educational psychology or content methodology courses (Wetzel, Foulger, Buss, & Lindsey, 2014). Furthermore, Niess (2005,
2009) called for the necessity of infusing technology into all courses in teacher education programs to establish a continuous program for developing pre-service teachers' TPACK over time. However, in reality, due to various contextual constraints, it is challenging for teacher education programs to provide every pre-service teacher with the needed preparation. Thus, it is worthy of exploring various strategies and approaches teacher educators have used for developing pre-service teachers' TPACK.

**Strategies for Developing Pre-service Teachers' TPACK**

Teacher educators have adopted various strategies to assist with the development of teachers' TPACK. Several strategies appear to be particularly promising: developing teacher educators' TPACK, providing pre-service teachers technology-rich method courses and field experiences (Polly et al., 2010), active involvement in technology-enhanced lesson or course design (Groth et al., 2009; Jang & Chen, 2010), and effective modeling on technology integration in the classroom (Lee & Hollebrands, 2008; Voogt et al., 2012). Besides these specific strategies, several approaches show positive outcomes, such as learning-by-design, case study approach, content-specific technology preparation, TPACK lesson planning, online resources, planning cycle, and assessment rubrics.

**Learning-by-design.** One approach that appears promising is learning-by-design (e.g., Figg & Jaipal, 2009, Koehler & Mishra, 2005; Koehler et al., 2007). To actively involve teachers in the process of developing their TPACK, Koehler and Mishra (2005) recommended a learning-technology-by-design approach. Using this approach, teachers, content experts, and technology specialists began their projects with authentic curriculum problems and then collaborated on designing technology-infused instruction together to solve the problems, thus developing their TPACK along the way (Koehler et al., 2007). Teacher educators also used instructional
approaches such as microteaching, active and professional inquiry, and self-reflection (Cavin, 2008; Dawson, 2007; Mouza & Wong, 2009; Pierson, 2008).

**Case study approach.** In 2007, Brantley-Dias et al. used a case-based instructional approach to develop pre-service teachers' pedagogical technology integration content knowledge (PTICK). They utilized a problem-based case approach in their courses for promoting technology integration. They asked pre-service teachers to analyze selected cases from a textbook, *Educational Technology in Action: Problem-based Exercises for Technology Integration* (Roblyer, 2004) according to their respective content areas. They also requested that the pre-service teachers submit four case study responses, four case study reflections, and three course reflection papers. Other authors continued this work of using cases to develop pre-service teachers' PTICK and concluded that it was a valid approach (Kinuthia, Brantley-Dias, & Clark, 2010).

**Content-specific technology preparation.** Many continue to call for more content-specific technology preparation for pre-service teachers. Niess (2005) describes a specific teacher education program, which was subject-specific content (mathematics and science) and focused on four themes: 1) research-based teaching and learning; 2) technology integration (TPCK); 3) PCK development; and 4) instructional practice integrated with campus-based coursework (p. 512). Similarly, Guerrero (2010) argued that technology may influence both pedagogy and content in mathematics as compared to other content areas. Thus, she proposed four components of Mathematical TPACK: 1) teachers' conception and use of technology, 2) technology-based classroom management, 3) depth and breadth of content, and 4) technology-based mathematics instruction (Guerrero, 2010). Guerrero’s argument highlighted the importance of understanding and developing content-specific TPACK, and that it impacts
teachers' practice in a more reform-oriented way. In another word, "TPACK embodies a teacher's ability to distinguish between the types of technology that are most suited to their content area and make decisions regarding its appropriate application" (Guerrero, 2010, p. 139). Jimoyiannis (2010) described a program designed for science teachers to develop their Technological Pedagogical Science Knowledge (TPASK). Similar to other scholars, he advocated providing content-specific preparation to help develop pre-service teachers’ TPACK.

**TPACK lesson planning.** Another practical approach utilized broadly in practice is developing pre-service teachers' TPACK through lesson planning. Roblyer and Doering (2010) called for teacher educators to teach pre-service teachers to use TPACK self-assessment when they began to plan their lessons. Harris, Mishra, and Koehler (2009) recommended that pre-service teachers could adopt a TPACK-based learning activities approach for lesson planning.

Harris and Hofer (2009a) suggested that teachers could adopt an activity-based, curriculum-keyed approach when they were planning technology-infused lessons, "that incorporates a systematic and judicious selection of technologies and teaching/learning strategies" (p. 100). They commented that although activity-based instructional planning existed in the history of education, "aligning learning activities with compatible educational technologies, and developing comprehensive, curriculum-keyed taxonomies of activity types that incorporate content, pedagogy, and technology knowledge, along with all their intersections, is the unique contribution of this TPACK development method" (Harris & Hofer, 2009a, p. 108). Using this approach, pre-service teachers select and combine curriculum-keyed teaching/learning activities and strategies first and then find complementary digital and nondigital tools and resources to fit their activities. However, Harris and Hofer (2009a) recognized that for pre-service teachers to adopt this approach initially would be challenging. Thus, a group of scholars
collectively created a comprehensive set of learning activity types taxonomies for each content area, such as K-6 literacy, mathematics, science, secondary English Language Arts, social studies, and world languages (Harris et al., 2009). The purpose of these learning activity types is to help pre-service teachers understand various approaches to technology integration regardless of their teaching philosophy or approach.

**Online resources.** Harris and Hofer continued their efforts by designing online resources to complement the taxonomies. In spring 2016, they designed and produced a customizable, modularized, TPACK-based online short course for developing elementary and secondary pre-service teachers' TPACK based on their years of research on the learning activity types. This online course is offered to teacher educators internationally as open educational resources (OERs). The course is self-paced and Creative Commons-licensed (Hofer & Harris, 2016).

Several other resources were created with the same purpose in mind. Figg created a 10-week gamified online learning module about TPACK (http://www.handy4class.com/h4c2011/tpack-teacher-quest-2015/). Zeitz and his students wrote a wiki book (https://en.wikibooks.org/wiki/TPACKing_for_a_Wonderful_Educational_Trip). Doering and colleagues (2009) incorporated TPACK into Geothentic (https://lt.umn.edu/geothentic/). Angeli and colleagues designed a series of curriculum- and classroom-based design scenarios (Angeli, Valanides, Mavroudi, Christodoulou, & Georgiou, 2015).

**Planning cycles for guiding pre-service teachers to design lesson plans.** Pre-service teachers need opportunities to design technology-infused lesson plans in order to develop their TPACK (Hutchison & Woodward, 2014a; Hutchison & Colwell, 2014; Leu et al., 2015). Three
sets of planning models were created (Harris & Hofer, 2009b; Hutchison & Woodward, 2014b; Hammond & Manfra, 2009).

Hammond and Manfra (2009) proposed the giving-prompting-making instructional model, which was specially designed for social studies pre-service teachers. This model guided pre-service teachers through the process of selecting the most appropriate use of technology for their lesson plans. If the pedagogical aim were giving, a teacher in the classroom gave or provided students with the information. If the teachers’ pedagogical aim is prompting, teachers became the facilitators during the students' engagement with various resources and materials. This approach aligns with the guidelines of constructivist models of teaching and learning (Vygotsky, 1978). Teachers use technology, especially emerging technologies, as an improvement of instruction to encourage problem-solving and inquiry-based learning. Finally, if the pedagogical aim were making, teachers adopt pedagogical strategies that extend constructivist models of learning and teaching by having students create content. In summary, Hammond and Manfra (2009) argued that "technology integration decisions should follow and extend from pedagogical decisions" (p. 174). Although the giving-prompting-making model was specially designed for social studies pre-service teachers, it could also guide pre-service teachers in other content areas.

Harris and Hofer (2009b) posited that lesson planning is comprised of five fundamental instructional decisions. These five steps are elements in their approach to Grounded Technology Integration pedagogical model: 1) Choose learning goals, 2) Make pedagogical decision, 3) Select activity types to combine, 4) Select assessment strategies, 5) Select tools/resources (Harris & Hofer, 2009b). Harris and Hofer also advocate that selecting educational technologies should be the last step during lesson planning, which emphasized that teachers should always begin their
lesson planning with a focus on content-based learning activities. Only until critical decisions were made about content and pedagogy should teachers begin the process of selecting appropriate technology tools. This approach assures that teachers will not focus on the technocentric approach to technology integration. Instead, they will purposefully select technology tools to support the content and pedagogical decisions.

Hutchison and Woodward (2014b) designed a recursive and reflective planning cycle especially for literacy teachers to design technology-enhanced lessons. This planning cycle is called the Technology Integration Planning Cycle for Literacy and Language Arts (see Figure 11). This planning cycle guides teachers through the lesson planning process when infusing technology into their literacy curriculum. Hutchison and Woodward (2014b) also highlight seven critical elements that a literacy teacher should consider during the instructional planning process. These planning cycles and guidelines are particularly useful to guide teacher educators’ and pre-service teachers’ practice.

Figure 11. The Technology Integration Planning Cycle for Literacy and Language Arts (Hutchison, & Woodward, 2014b, p.459).
The efforts in this area are numerous as teacher educators have applied many strategies and approaches focused on developing pre-service teachers' TPACK. Though more work is still needed in practice to provide adequate and appropriate technology integration preparation to pre-service teachers, these contributions should not be overlooked.

**Conclusion**

The TPACK framework as a conceptual framework has provided researchers with a lens for theoretical exploration and an analytical tool for investigating teachers' knowledge. The TPACK framework provides teacher educators and teachers with a common language to discuss the needed knowledge for effective technology integration. Still, the field needs more research focused on TPACK-related studies. In this section, some possible next steps are discussed.

A Google Scholar search on the usage of the TPACK frameworks over the years was conducted (see Figure 12). It is evident that the TPACK framework has been accepted and used by a large number of scholars since its introduction. Comparatively, the ICT-TPCK framework is cited, but not to the same degree. This finding represents the debate in the field on whether TPACK is integrative or transformative. More empirical studies should be conducted to provide evidence to provide evidence for these two viewpoints. Newly conceptualized frameworks demonstrate significant efforts had been made to cross-pollinate the TPACK framework with other theories and models in education and/or from other disciplines. These conceptualization efforts show a trend that the TPACK framework is becoming more domain-specific and foreshadow the possibilities of adapting the original framework for different fields. Empirical research using these domain-specific TPACK frameworks are needed to keep moving the field forward to better inform the development of pre-service teachers’ TPACK.
Figure 12. TPACK frameworks discussed in the literature over the years.

Angeli, Valanides, & Christodoulou (2016) suggested that researchers should continue to work on TPACK research, especially how each knowledge domain contributed to the development of TPACK, and to provide further clarification of the framework. This in turn would provide a more in-depth understanding of the practical measures for the subscales of TPACK framework. Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein, and Glutting (2013) argued that we should look into “...the possibility of adopting a transformative perspective in the examination of TPACK as a unique knowledge body that is more than the sum of its parts” (p. 357). Therefore, further definition and operationalization of the TPACK domain is critical to making further distinctions between and among the knowledge domains. Such investigations would produce clearer distinctions among TCK, TPK, and TPACK with considerations of content area characteristics (Archambault & Crippen, 2009; Brantley-Dias & Ertmer, 2013; Graham, 2011). It would also be important to investigate whether the TPACK domains look different for pre-service, novice, and experienced teachers.

Another important next step is to further theorize the “context” component of the TPACK framework so researchers might gain a shared understanding and be able to apply it to their work. Once this understanding is achieved, researchers could begin to build this into some
widely used TPACK instruments (e.g., Schmidt et al., 2009) and develop measures for specific contexts. Researchers could draw from the work of Porras-Hernandez and Salinas-Amescua (2013), as well as other frameworks (e.g., Angeli & Valanides, 2009; Doering, Veletsianos, Scharber, & Miller, 2009; Kelly, 2008a, 2008b; Saad, Barbar, & Abourjeili, 2012) to help guide this work. Thus, it would be valuable to examine how and why contextual factors might impact teachers’ TPACK.

Further examination of the TPACK domains is important, but additional research that covers the entire scope of a teacher education program is needed. Longitudinal studies that measures pre-service teachers’ development of TPACK at different times during their teacher education program are needed, as well as adding triangulated representations of pre-service teachers' TPACK (Hofer & Grandgenett, 2012). Kopcha et al. (2014) reported that survey and rubric scores were not aligned in most studies, and the correlation scores among the domains were weak. Similar results were also reported by Agyei and Keengwe (2014). They found that pre-service teachers' performance scores, which indicated their learning outcomes, did not correlate with their self-reported scores of TPACK. Results such as these warrant further investigation.

More empirical evidence is needed to explain whether TPACK is an integrative or transformative concept, as well as whether it is domain-general or domain-specific. Mishra and Koehler's (2006) Venn diagram indicated that TPACK is an integrative concept. However, some research defines TPACK as transformative (e.g., Valanides & Angelis, 2008a, 2008b). Other researchers (Harris et al., 2010; Niess, 2011) began the conversation of whether TPACK is domain-general or domain-specific. More empirical evidence is needed to further the discussion. Overall, the implications of TPACK research is profound since it will directly affect how
teachers will be prepared for technology integration in teacher education programs (Angeli et al., 2016).

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CHAPTER 3. LONGITUDINAL STUDY OF PRE-SERVICE TEACHERS
DEVELOPMENT OF TPACK

Abstract: The purpose of this longitudinal study was to investigate the trend of pre-service teachers’ pre-technological pedagogical content knowledge (TPACK) scores, their cluster assignment, and post-TPACK and TPACK-development scores after completing a required educational technology course over the span of nine academic years (Mishra & Koehler, 2006). A two-step cluster analysis was used to group pre-service teachers into distinct groups based on their pre-TPACK scores. A two-cluster model was found to be a good fit. Thus, pre-service teachers were grouped into cluster 1 (lower pre-TPACK scores) and cluster 2 (higher pre-TPACK scores). Independent-sample t-tests were run to test whether there were differences in the post-TPACK and TPACK-development scores between the two clusters after the completion of the educational technology course. Findings revealed that cluster 2 pre-service teachers had higher post-TPACK scores than cluster 1 pre-service teachers. However, cluster 1 pre-service teachers had higher TPACK-development scores. In the end, cluster 1 pre-service teachers still had lower post-TPACK scores compared to cluster 2 pre-service teachers. Results from this study demonstrate that pre-service teachers’ prior knowledge is a key factor and will impact their development of TPACK. The findings also pinpoint the need to investigate the interaction effects of the prior knowledge, course design, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores.
**Keywords:** technological pedagogical content knowledge (TPACK), prior knowledge, pre-service teachers, cluster analysis, trend, multi-year research
**Introduction**

Years ago, Seymour Papert promoted the concept of kid power and commented in 1999 interview about how computers fundamentally change the way kids learn. He said,

> I think the technology serves as a Trojan horse all right, but in the real story of the Trojan horse, it wasn't the horse that was effective, it was the soldiers inside the horse. And the technology is only going to be effective in changing education if you put an army inside it, which is determined to make that change once it gets through the barrier. (Schwartz, 1999)

Almost twenty years later, this concept is still revolutionary. Technology is not the Trojan horse; it is the students who use it who are the political force for making social change. However, to get the kids inside the Trojan horse, teachers need to join them and be inside the horse along with them more than ever. In particular, teachers need to work side-by-side to guide students on how to think about using technology as a tool to make powerful social change. Even so, how do we get teachers inside this Trojan horse called technology and become a force for educational renewal and change? The answer to this question is self-evident. Preparing pre-service teachers for integrating technology in classrooms is a critical, yet difficult task for most teacher education programs. The experiences pre-service teachers encounter during their teacher preparation programs have profound implications for equipping them with the necessary skills and knowledge they need to become productive technology-using educators.

The Technological Pedagogical Content Knowledge (TPACK) conceptual framework is used by many in the educational technology field to undergird research conducted in this area (Mishra & Koehler, 2006). Specifically, several investigate how teachers’ knowledge develop in and among the knowledge domains and then examine how this impacts their technology use and
integration (Willermark, 2017). Guided by this framework, many researchers have focused on pre-service teachers' development of TPACK (Tondeur, van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012; Willermark, 2017). Researchers have conducted a number of studies that measure how pre-service teachers develop TPACK during their teacher education programs (e.g., Finger, Jamieson-Proctor, & Albion, 2010; Jang & Chen, 2010; Schmidt et al., 2009; Ward & Overall, 2010). Moreover, some researchers compare the effectiveness of a stand-alone educational technology course to that of a technology-infused teacher education program (e.g., Buss, Wetzel, Foulger, & Lindsey, 2015; Foulger, Buss, Wetzel, & Lindsey, 2012, 2015; Wetzel, Buss, Foulger, & Lindsey, 2014). Fewer yet have particularly focused on pre-service teachers' prior knowledge and the impacts prior knowledge has on their development of TPACK during the teacher education program (Koh & Chai, 2014). Thus, the purpose of this study was to investigate whether pre-service teachers have different levels of prior knowledge when entering a required, introductory educational technology course and how that impacts pre-service teachers' development of TPACK during this course. This study utilized a longitudinal approach in which data were collected and analyzed from 1,246 pre-service teachers over a span of nine academic years (2008–2017).

**Theoretical and Conceptual Frameworks**

In this section, the theoretical and conceptual frameworks used to guide this study will be shared. Both, constructionism and the TPACK framework, is used to help situate this research within the context of pre-service teachers' prior knowledge and their development of TPACK during the teacher education program.
Constructionism

The originator of constructionism is Seymour Papert, who was a student of Jean Piaget, and a key contributor to constructivism. Papert extended Piaget's epistemological theory of constructivism and adapted it into the theory of constructionism. The purpose of this adaptation was to reinvent constructivism to make it compatible with technology integration in classrooms and emphasize the art of learning, such as learning-by-design, problem-based learning, project-based learning, and connected learning (Papert & Harel, 1991). In short, constructionism is a theory of learning that states people learn by utilizing their prior knowledge to acquire more knowledge and by making, inventing, doing, and creating in a tangible, sharable, and concrete way (Papert, 1980; Papert & Harel, 1991).

Related to teaching practice, Papert was a big proponent of student-centered discovery learning (Papert, 1990). Papert also advocated for bringing technology to the classroom and giving students the power to generate big ideas. Ultimately, constructionism supports learner-centered pedagogical models that meaningfully integrate technology as a tool for students to tinker and make. It redirected peoples' focus from what is constructed cognitively to what is created physically and learned through this process of doing and making. Meanwhile, it intrigues people to find alternative understandings of the relationships between learning, the educational system, and society as a whole.

In practice, educators who hold the constructionist point of view design learning experiences by providing students with opportunities to build, create, investigate, and experiment by themselves. These educators place the power in students' hands by emphasizing the importance of learning by creating. They learn from the eight big ideas of Seymour Papert to guide their everyday practice, which are: 1) learning by doing, 2) using technology as building
materials, 3) hard "fun", 4) learning to learn, 5) taking a right and proper time for the job, 6) you cannot get it right without getting it wrong, 7) do unto ourselves what we do unto our students, and 8) entering and navigating the digital world (Martinez & Stager, 2013; Schwartz, 1999).

For this study, the researcher was a member of the instructional team who co-taught the required educational technology course. She also participated in a redesign of the course during 2013. She aligns herself with the constructionism theory of learning and believes that the best way for pre-service teachers to learn about teaching, especially with technology, is to create lesson plans, projects, artifacts, and instructional materials through hands-on activities, and then reflect on their teaching and learning from both students' and teachers' perspectives. Accordingly, the instructional team redesigned the course in a way that incorporated the eight big ideas from Papert (Schwartz, 1999). It was envisioned that pre-service teachers enrolled in this course would acquire TPACK by creating projects, artifacts, and lesson plans using a variety of emerging educational technologies. Later on, pre-service teachers shared their projects and artifacts in the class and were continually asked to reflect on their learning processes from multiple perspectives. More elaborations will be provided about the course in the methodology section.

The TPACK Framework

The TPACK framework originated from the PCK framework proposed by Shulman (1986, 1987) included content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK). Nearly a decade after the initial release of the PCK framework, several educational technology researchers began to conceptualize what knowledge teachers needed for meaningful technology integration into the curricula (Angeli & Valanides, 2005; Hughes, 2005; Keating & Evans, 2001; Koehler & Mishra, 2005a, b; Lundeberg, Bergland,
In 2006, Mishra and Koehler proposed the Technological Pedagogical Content Knowledge (TPCK) framework. The TPCK framework added four new domains of teacher knowledge to the original PCK framework, technological knowledge (TK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPCK) (see Figure 1). In 2007, TPCK was changed to TPACK for easier pronunciation and more emphasis on the connotation of being a "Total PACKage" (Thompson & Mishra, 2007, p. 38). At the intersection of this Venn diagram lies technological pedagogical content knowledge (TPACK), which is the knowledge teachers use when integrating technology into their teaching in any subject area (Schmidt et al., 2009).

Figure 1. The TPACK framework illustration was adapted from. Reproduced by permission of the publisher, © 2012 by tpack.org.

Over a period of twenty years, the TPACK framework has been widely accepted and adopted by educational stakeholders as a result of the continuous contributions from a group of scholars who further conceptualize and examine the framework (Angeli, Valanides, & Christodoulou, 2016). The researchers conclude that TPACK is "situated, complex, multifaceted,
integrative and/or transformative" (Chai, Koh, & Tsai, 2013, p. 32). Overall, the TPACK framework provides a common language to help conceptualize the knowledge domains teachers tap into when they integrate technology into their teaching. It also helped guide this researcher to conceptualize what types of prior knowledge pre-service teachers brought with them and could potentially develop during their preparation in the teacher education program. Therefore, for this research, in particular, the TPACK framework guided the researcher while investigating the specific knowledge domains related to pre-service teachers’ prior knowledge and development of TPACK.

**Literature Review**

21st Century teachers should be able to meaningfully integrate technology into their teaching (Tondeur et al., 2012). Thus, teacher education programs need to take responsibility for developing pre-service teachers’ knowledge of content, pedagogy, and technology, and more importantly, TPACK, so that they can become effective 21st Century teachers (Mishra & Koehler, 2006). In addition, teacher educators should also be responsible for developing pre-service teachers' TPACK strategic thinking, which is "knowing when, where, and how to use domain-specific knowledge and strategies (Shavelson, Ruiz-Primo, Li, & Ayala, 2003) when guiding student learning with appropriate information and communication technologies" (Niess, 2011, p. 307). However, this is a challenging task for most teacher education programs. Thus, to provide context for this study, a review of prior knowledge literature will be provided, underlining the importance of understanding pre-service teachers' prior knowledge and considering its impact while completing a teacher education program. A review of how teacher education programs prepare pre-service teachers to develop their TPACK, as well as highlights
from the studies conducted on measuring pre-service teachers' development of TPACK, will follow.

**Prior Knowledge and its Impact on Knowledge Development**

Contemporary learning theories view learning as a process where people continually construct new knowledge based on what they already know and believe (e.g., Cobb, 1994; Piaget, 1973, 1977; Piaget & Cook, 1952; Piaget & Inhelder, 1973; Piaget & Kamii, 1978; Vygotsky, 1978, 2012). In this sense, learners possess prior knowledge when entering a new learning environment. The prior knowledge learners bring with them consists of background knowledge, intellectual development, cultural background, and general experiences and expectations (Dochy, Segers, & Buehl, 1999). Prior knowledge is potentially relevant to acquiring new knowledge (Biemans & Simons, 1996). To be more specific, learners' prior knowledge and experiences greatly affect how they perceive and organize new information and make connections between ideas (Dochy et al., 1999).

Two particular strategies have been identified to describe how learners use prior knowledge to acquire new knowledge - assimilation and accommodation. Through assimilation, learners fit new information into existing schema, while using accommodation, learners change existing schema to fit new information (Dochy & Alexander, 1995). Concerning prior knowledge's effects on learning, researchers have acknowledged the powerful impact of learners' prior knowledge on subsequent learning and development (Dochy & Alexander, 1995; Dochy, Segers, & Buehl, 1999; National Research Council, 2000). Furthermore, scholars agree that the assessment of prior knowledge could shed light on the most needed instruction and scaffolding for different individuals' learning needs (Dochy, 1992; National Research Council, 2000).
Relatedly, teachers' prior knowledge moderates their future learning (Borko & Putnam, 1995, 1996; Bransford & Schwartz, 1999). Teachers, as learners, understand, interpret, question, evaluate, and acquire new knowledge by making connections to their prior knowledge and experiences (Hughes, 2005). For example, King (2002) found that teachers' lack of experiences with technology help them realize the need to learn, prompt the engagement in technology learning experiences, which, in turn, “cause adults to question their knowledge base and to change their actions” (p. 2087). King also documented how teachers transformed their perspectives on learning and teaching after questioning about their prior knowledge, such as shifts from teacher-centered to student-centered perspectives, development of a worldview of education, or changes in instructional preparation. Similarly, Hughes (2005) postulated that this kind of change, which resulted from learning experiences, offered teachers the opportunities to recognize their prior knowledge, as well as impelled them to change their beliefs and acquire more knowledge. These findings on prior knowledge have important implications for teacher educators to contemplate on how to cultivate pre-service teachers' development of TPACK.

It is worth looking closely at the composition of pre-service teachers’ prior knowledge. Guided by the TPACK framework, it postulates that pre-service teachers have or can acquire seven types of knowledge (Mishra & Koehler, 2006). These knowledge domains are CK, PK, TK, PCK, TCK, TPK, and TPACK, as outlined in the TPACK framework. These knowledge domains help form pre-service teachers' conceptualization of technology integration in the curricula and the role they play in a technology-infused educational system. In this study, the definitions from Schmidt et al. (2009) are used to conceptualize the seven TPACK domains.

It is easier to understand how pre-service teachers developed their CK and TK before entering a teacher education program. However, it is worthy of looking into how pre-service
teacher acquired their PK over the years. Pre-service teachers' prior knowledge about the pedagogy mainly comes from the modeling they experienced when they were students in the K-12 setting, college, and from other formal educational experiences. As suggested by Keating and Evans (2001), modeling can be defined as "those messages received by students through formal, stated curriculum; the actions of their teachers, professors, and cooperative teachers; and the underlying social relations they perceive in the use of technology in education" (p. 1672). Different experiences of using technology and modeling undoubtedly will engender various preconceptions about learning and teaching with technology. Pierson (2001) reported that teachers possess different levels of pedagogical expertise and technology proficiency, which affect how they perceive and approach technology integration.

Koh and Chai (2014) investigated pre-service teachers' prior knowledge and their development of TPACK before and after completing a module on designing TPACK lesson plans. Using cluster analysis, they found that all pre-service teachers developed TPK, TCK, and TPACK. Nevertheless, interestingly, pre-service teachers who were more confident developed more TPACK compared to those who were less confident. Koh and Chai’s results called for more research on whether differentiated instruction is needed for pre-service teachers during the process of developing their TPACK. Given that prior knowledge is an essential variable for learning and knowledge development, it is important to assess the effect of prior knowledge on pre-service teachers' development of TPACK and whether individuals who possess a different amount of prior knowledge need differentiated instruction. Thus, the purpose of this research was to examine how pre-service teachers’ pre-TPACK scores impacted their post-TPACK and TPACK-development scores. A review of how teacher educators prepare pre-service teachers for technology integration will help provide some context for this investigation.
Preparing Pre-service Teachers for Technology Integration

Preparing pre-service teachers for technology integration became a priority in the mid-1990s due to the benefits technology brought to K-12 education (Wentworth & Earle, 2003). Beck and Wynn (1998) described various approaches teacher education programs were using to prepare pre-service teachers for technology integration. Beck and Wynn placed these approaches on a continuum. At the left end of the continuum, a stand-alone foundational educational technology course is offered, while at the right end of the continuum, a transformative approach suggests the integration of technology into all courses within a teacher education program (Duhaney, 2001). Beck and Wynn (1998) postulated that a transformative change to infuse technology into the whole program would be ideal for preparing pre-service teachers for technology integration.

Teacher educators still face many challenges in finding and implementing practical approaches for preparing pre-service teachers to use and integrate technology (Goktas, Yildirim, & Yildirim, 2008). In practice, preparing pre-service teachers to use technology has mostly been offered in a stand-alone educational technology course (Leeman, 2013; Polly, Mims, Shepherd, & Inan, 2010). Kleiner, Thomas, and Lewis (2007) surveyed 1,439 teacher education programs in the United States and found that more than 85% of these programs offered pre-service teachers a stand-alone educational technology course ranging from one to four credits. It is not a coincidence that most teacher education programs select this approach. Institutional barriers such as insufficient curriculum time, limited time for planning, examination constraints, technology planning and leadership, training staff, access to resources, inconsistent technology knowledge among teacher educators, prevent most teacher education programs from effectively infusing technology into every course (Chai, Koh, & Tsai, 2013; Goktas, Yildirim, & Yildirim, 2008;
Groth, Spickler, Bergner, & Bardzell, 2009; Harris & Hofer, 2011; Nicholas & Ng, 2012; Tondeur et al., 2012).

Many teacher education programs are designed with the expectations that pre-service teachers should be able to infuse technology into their teaching after taking a stand-alone educational technology course (Rutowski et al., 2002). Although many teacher education programs prepare pre-service teachers by using the stand-alone educational technology course, that course has found to be mainly focused on using technology for personal productivity and information presentation (Gronseth et al., 2009; Polly, Mims, Shepherds, & Inan, 2010). In addition, the stand-alone educational technology course is usually disconnected from the content methodology courses offered in preparation programs (Friedman & Kajder, 2006; Kay, 2006). This disconnect typically results in the lack of the modeling pre-service teachers need to effectively integrate technology into subject-area teaching, as well as a paucity of practices to infuse technology into lesson planning (Chai, Koh, & Tsai, 2013; Chai, Koh, Tsai, & Tan, 2011; Han & Finkelstein, 2013; Horzum, 2013; Hughes, 2013; Pamuk, 2012; Semiz & Ince, 2012; Tokmak, Incikabi, & Ozgelen, 2013; Young, Young, & Hamilton, 2013). Results from such studies noted that the lack of pedagogical knowledge inhibited pre-service teachers' technology integration, and in turn, their overall development of TPACK in a stand-alone educational technology course (Chai, Koh, & Tsai, 2010; Pamuk, 2012). Still, pre-service teachers often stated that they do not feel prepared for infusing technology into their teaching even after taking such a course (Tondeur et al., 2012). Thus, a stand-alone educational technology course might not be enough to provide pre-service teachers with the necessary targeted, simultaneous, and authentic content and pedagogy preparation, which tends to emerge organically from methods courses (Buss et al., 2015).
Alternatively, some teacher education programs have focused their efforts on integrating technology into educational psychology or content methodology courses, including practicums and fieldwork, giving pre-service teachers opportunities to focus on subject area content knowledge and pedagogical knowledge (Brubacher & Wilson, 2009; Wetzel et al., 2014). For example, Niess (2005) infused technology in various courses focused on math and science content. She called for the necessity of infusing technology into all courses to establish a continuous cycle for developing pre-service teachers' TPACK. Teacher education programs like this hold the belief that focusing on developing pre-service teachers' TPACK with special considerations to subject-sensitive content and pedagogy is more important than only preparing pre-service teachers for fluency in using technological tools (Niess, 2011). Notably, some researchers found that using this approach of integrated preparation was more cognitively and developmentally appropriate for pre-service teachers, as this approach was more likely to foster technology skills that pre-service teachers would use in K-12 teaching (Pierson & Thompson, 2005; Tondeur et al., 2012).

Pre-service Teachers' Development of TPACK in Teacher Education Programs

There have been a large number of studies conducted investigating the development of pre-service teachers' TPACK (Archambault, 2016; Chai, Koh, & Tsai, 2016; Willermark, 2017). Several specially examined pre-service teachers' development of TPACK after taking a stand-alone educational technology course (Chai et al., 2011; Koh & Divaharan, 2013; Schmidt et al., 2009). In 2009, Schmidt and colleagues reported that pre-service teachers developed all seven TPACK domains after taking a stand-alone educational technology course, especially TK, TCK, and TPACK. Additional researchers also maintained that such a course had positive impacts on
developing pre-service teachers' TPACK, confidence, and technology skills (Abbitt, 2011; Bai & Ertmer, 2008; Chai, Koh, & Tsai, 2010; Foulger et al., 2012; Graham, Borup, & Smith, 2012).

Some studies sought to examine the correlations between the TPACK knowledge domains. Chai et al. (2011) found that after taking an ICT course, the relationship between pre-service teachers' PK and TPACK was insignificant, while the relationship between CK and TPACK became significant. These findings stress the need for connecting content and pedagogical knowledge during the stand-alone technology course to maximize pre-service teachers' development of TPACK.

In practice, some teacher educators have been applying various teaching strategies for preparing pre-service teachers to integrate technology in meaningful ways and in different contexts. For example, Angeli and Valanides (2005) created an instructional system design (ISD) model to be used in teacher preparation programs to develop pre-service teachers' information and communication (ICT)-related pedagogical content knowledge (PCK). Later, these researchers followed up by offering pre-service teachers Technology Mapping (TM) activities and peer assessment learning experiences (Angeli & Valanides, 2009). Niess (2005) promoted a program-wide technology-infused approach for developing pre-service teachers' content-specific TPCK, emphasizing instructional modeling. Mishra and Koehler (2006) utilized a learning technology by design method to prepare teachers for technology integration in actual learning environments. Others paired pre-service teachers with experienced teachers for collaborative design work (Brown & Warschauer, 2006; Groth et al., 2009). Brantley-Dias, Kinuthia, Shoffner, de Castro, and Rigole (2007) adopted a case-study approach for studying pre-service teachers’ development of pedagogical technology integration content knowledge (PTICK). Another typical approach taught pre-service teachers to reflect upon their teaching using the
TPACK framework (Cavin, 2008; Pierson, 2008). Likewise, Mouza and Wong (2009) proposed a TPACK-based case development strategy that pre-service teachers used to reflect and inquire about their teaching.

Using the TPACK framework to assist with lesson planning was another widely-used approach for developing pre-service teachers' TPACK (Harris & Hofer, 2009; Harris, Mishra, & Koehler, 2009). A variety of online courses and resources were later developed to offer instruction on how to design TPACK lessons (Angeli, Valanides, Mavroudi, Christodoulou, & Georgiou, 2015; Bannister, Ross, & Schellhas, 2009; Doering, Veletsianos, Scharber, & Miller, 2009; Harris, Grandgenett, & Hofer, 2010; Hofer & Harris, 2016). Several found success in using varied lesson plan approaches and reported knowledge gains in pre-service teachers' TPACK (Angeli & Valanides, 2005; Brantley-Dias et al., 2007; Mishra & Koehler, 2006; Niess, 2005).

Few studies have systematically investigated pre-service teachers' prior knowledge and how the differences in prior knowledge might impact their development of TPACK. It seems relevant to study pre-service teachers’ prior knowledge and its impact on their development of TPACK, and then how pre-service teachers’ acquire TPACK at different stages or times during a teacher education program (Cox, 2008). The results will help teacher educators plan the coursework and field experiences needed to prepare pre-service teachers for technology integration. Roblyer and Doering (2010) promoted using self-assessment of prior knowledge as a logical first step. This longitudinal study will investigate pre-service teachers' self-reported pre-TPACK scores from 2008 to 2017 and its impact on their post-TPACK and TPACK-development scores. Four research guided this longitudinal study:
1. Do pre-service teachers’ average pre-TPACK scores significantly and substantially change from 2008 to 2017?

2. What are pre-service teachers’ clusters based on their pre-TPACK scores?

3. Do pre-service teachers develop TPACK after taking the required educational technology course?

4. Are there differences in pre-service teachers’ post-TPACK and TPACK-development scores according to pre-service teachers’ assignment to clusters based on their pre-TPACK scores?

Methodology

In this section, the research context and course design are introduced. Then, information about the survey instrument and data collection, participants, and data analysis are provided.

Research Context

This study is situated in a required 3-credit introductory educational technology course for pre-service teachers in a teacher education program at a large Midwestern land-grant university. In this course, a lead instructor and several lab instructors form an instructional team with shared teaching responsibilities. Every week, the lead instructor teaches two 50-minute lectures to introduce major concepts and theories in the field of educational technology. The lab instructors facilitate the weekly lab sections by adopting a project-based approach. Pre-service teachers are required to attend both lectures and labs. Some major assessments for the course are hands-on projects, reflection papers, a technology lesson plan, and an online course portfolio with an accompanying final reflection paper.

Course Design

The required educational technology course is a foundational course in this teacher
education program, which lays the groundwork for preparing pre-service teachers for technology use and integration. It has been taught by the same lead instructor for more than nine years. This lead instructor has continuously revised the course over the past decade. Prior to 2014, the course focused mainly on introducing basic knowledge of educational technology, as well as different types of educational technologies that could be used in PK-6 classrooms. Over the first five years, most course development focused on substituting and adding emerging technologies into the course.

In 2013, the instructional team reviewed the course to assess how the content aligned with what was being taught in the content area methods courses in the program. The instructors saw the need to include more content-specific examples and share pedagogical aspects that were applicable across or targeted individual subject areas. Thus, a major course redesign was carried out for both theoretical and practical reasons. Theoretically, the instructors aimed to redesign the course to closely align with the TPACK framework. In particular, the highly-prioritized goal was to cultivate pre-service teachers’ development of TPACK and TPACK application to PK-6 classroom settings. Because most pre-service teachers enter the course with limited content and pedagogy knowledge, the instructors aspired to lay some groundwork for developing their CK and PK, which in turn would make a smooth transition to content area methods courses. The course content was organized around five major instructional modules, Module 1. Introduction to Educational Technology, Module 2. Technology Integration in Math, Module 3. Technology Integration in Literacy, Module 4. Technology Integration in Science, and Module 5. Technology Integration in Social Studies. The redesigned course was first taught Fall 2014 semester.

Survey Instrument and Data Collection

A validated instrument called the Survey of Pre-service Teachers' Knowledge of
Teaching and Technology (Schmidt et al., 2009) was administered to collect data from 1,246 participants. These participants voluntarily participated each semester and data were collected for nine academic years (i.e., 18 semesters). This particular survey was designed primarily for pre-service teachers having either Early Childhood or Elementary Education majors. This survey uses eight items to gather demographic information and 46 Likert scale items to measure the seven TPACK domains. Specifically, twelve questions address CK, seven questions address PK, six questions address TK, four questions address PCK, four questions address TCK, five questions address TPK, and eight questions address TPACK. The internal reliability (coefficient alpha) of the seven TPACK subscales ranged from .75 to .92 (Schmidt et al., 2009).

The data collection process included sending out the links of the pre-surveys to the participants during the first week of the course each semester. Participants accessed the links through the learning management system, and they filled out the surveys using an online survey tool. On the first page of the survey, an informed consent form provided participants with detailed descriptions of the study's purpose and the voluntary nature of the research. Participants who participated completed the survey within 15 to 20 minutes. Post-survey links were sent during the last week of the course (Week 15) and participants went through the same process to complete the surveys. Multi-year data from eighteen semesters were collected from participants enrolled in the course. Since the survey items remained the same over the 18 semesters, data were merged into one dataset for further analysis.

Participants

The participants were 1,246 pre-service teachers enrolled in the required educational technology course. Among these 1,246 pre-service teachers, 1,115 (89.49%) were female, and 131 (10.51%) were male. Most of them were 18–22 years old (1,139, 91.41%), 76 (6.10%) were
23–26 years old, 18 (1.44%) were 27–32 years old, and 13 (1.04%) were older than 32 years old. Moreover, 267 (21.43%) pre-service teachers were freshmen, 591 (47.43%) were sophomores, 309 (24.80%) were juniors, and 79 (6.34%) were seniors. These pre-service teachers had various majors: 222 (17.82%) majored in Early Childhood Education (ECE), 974 (78.17%) majored in Elementary Education (EL ED), and 50 (4.01%) were enrolled in another major. By the time these pre-service teachers took the course, 515 (41.33%) had practicum experiences in the PK-6 classrooms, while 731 (58.66%) had not been in a practicum experience. In addition, 146 (11.72%) pre-service teachers were enrolled in the Learning Technologies Minor, a minor focused on educational technology and offered in this teacher education program.

Data Analysis

The construct validity of the TPACK survey was examined (Schmidt et al., 2009). The internal consistency reliabilities of the seven survey scales were computed by calculating the Cronbach's coefficient alpha (α). For the pre-survey, the Cronbach's coefficient alphas (α) of the seven scales ranged from .80 to .92 (i.e., TK: α = .86; CK: α = .80; PK: α = .87; PCK: α = .83; TCK: α = .87; TPK: α = .82; TPACK: α = .92). For the post-survey, the Cronbach's coefficient alphas (α) of the seven scales ranged from .86 to .91 (i.e., TK: α = .86; CK: α = .86; PK: α = .86; PCK: α = .86; TCK: α = .87; TPK: α = .88; TPACK: α = .91). According to Nunnaly and Berstein (1994), a Cronbach's alpha (α) of .70 is considered acceptable for exploratory studies, .80 for basic research, and .90 for applied scenarios. The scales for this survey could be regarded as good for applied scenarios (George & Mallory, 2003; Lance, Butts, & Michels, 2006). The survey was a valid and reliable tool for measuring the seven TPACK subscales examined in this study.

To answer the first research question, descriptive analysis and one-way ANOVA tests
were performed to investigate the trend in the pre-service teachers’ prior knowledge over the 18 semesters. To answer the second research question, two-step cluster analyses were conducted for categorizing pre-service teachers into groups based on their pre-TPACK scores. Cluster analysis is a multivariate statistical analysis used for grouping objects based on their characteristics, which is a type of classification analysis particularly helpful for data mining and system identification (Abonyi & Feil, 2007). This technique was used in this study to classify pre-service teachers into clusters that were relatively homogeneous within themselves and heterogeneous between each other by using their pre-TPACK scores. Choosing an appropriate similarity measure for the cluster analysis is vital for producing clusters with high intra-class similarity and low inter-class similarity, which helps discover some or all of the hidden patterns existing in the dataset. To establish the groups of pre-service teachers for further analysis, a method called two-step cluster analysis, which was a combination of both hierarchical and nonhierarchical cluster analyses, were utilized. Using this algorithm produced several beneficial outcomes. First, the method helped create clusters based on both categorical and continuous variables. Second, the method helped select the number of clusters. Third, the method had the ability to analyze a large dataset efficiently (Abonyi & Feil, 2007). After conducting the cluster analysis, an independent sample t-test was used to confirm that there were differences among the clusters for each variable. If there were no differences among clusters, the variable would be removed from the analysis, and another round of cluster analysis began until a good fit model was found. To answer the third research question, paired-sample t-tests were conducted to see whether pre-service teachers developed TPACK after course completion. To answer the fourth research question, independent sample t-tests were conducted to compare the post-TPACK and TPACK-development scores between the clusters.
Results

In this section, the results will be presented. The section will be organized in a sequential order that follows the statistical analyses for each research question.

**Research Question 1: Do pre-service teachers' average pre-TPACK scores significantly and substantially change from 2008 to 2017?**

To answer research question 1, descriptive analysis and one-way ANOVA tests were run on the multi-year data collected using the TPACK survey (Schmidt et al., 2009). Descriptive analysis was conducted to provide an overview of the trend over the years (see Table 1). In general, increases were found in all seven TPACK subscales (\(\text{CK}_{\text{pre}} = 44.07, \text{CK}_{\text{post}} = 47.00\); \(\text{PK}_{\text{pre}} = 26.06, \text{PK}_{\text{post}} = 28.35\); \(\text{TK}_{\text{pre}} = 21.04, \text{TK}_{\text{post}} = 23.48\); \(\text{PCK}_{\text{pre}} = 14.22, \text{PCK}_{\text{post}} = 15.57\); \(\text{TCK}_{\text{pre}} = 13.03, \text{TCK}_{\text{post}} = 16.29\); \(\text{TPK}_{\text{pre}} = 19.33, \text{TPK}_{\text{post}} = 21.53\); \(\text{TPACK}_{\text{pre}} = 28.41, \text{TPACK}_{\text{post}} = 33.06\)). As seen in Figure 2, all seven prior knowledge subscales remained relatively stable over the nine year time period.

![Figure 2. Pre-service teachers' average pre-TPACK scores over nine academic years.](image-url)
Table 1

*Pre-service Teachers' TPACK Scores (n = 1,246)*

<table>
<thead>
<tr>
<th>Year</th>
<th>Pre-service teachers' TPACK subscales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1 (n = 180)</td>
<td>CK</td>
</tr>
<tr>
<td>Pre</td>
<td>n</td>
</tr>
<tr>
<td>Post</td>
<td>n</td>
</tr>
<tr>
<td>Year 2 (n = 176)</td>
<td>44.30</td>
</tr>
<tr>
<td></td>
<td>(5.58)</td>
</tr>
<tr>
<td>Year 3 (n = 181)</td>
<td>44.09</td>
</tr>
<tr>
<td></td>
<td>(5.05)</td>
</tr>
<tr>
<td>Year 4 (n = 114)</td>
<td>43.61</td>
</tr>
<tr>
<td></td>
<td>(5.18)</td>
</tr>
<tr>
<td>Year 5 (n = 149)</td>
<td>44.30</td>
</tr>
<tr>
<td></td>
<td>(4.71)</td>
</tr>
<tr>
<td>Year 6 (n = 83)</td>
<td>42.58</td>
</tr>
<tr>
<td></td>
<td>(5.10)</td>
</tr>
<tr>
<td>Year 7 (n = 136)</td>
<td>44.84</td>
</tr>
<tr>
<td></td>
<td>(4.80)</td>
</tr>
<tr>
<td>Year 8 (n = 97)</td>
<td>44.29</td>
</tr>
<tr>
<td></td>
<td>(5.57)</td>
</tr>
<tr>
<td></td>
<td>(5.17)</td>
</tr>
<tr>
<td></td>
<td>(4.98)</td>
</tr>
</tbody>
</table>
Next, one-way ANOVA analyses were conducted to test whether there were statistically significant differences in the seven pre-TPACK subscales over the years (see Table 2).

Statistically significant differences were found in four out of the seven subscales (CK, TK, TPK, and TPACK). Pre-service teachers' pre-CK scores were statistically significantly different in different cohorts, $F(8, 1237) = 2.50, p < .01, \eta^2 = .02$. However, Tukey post hoc test results revealed that there were no statistically significant differences in pre-service teachers' pre-CK scores in different cohorts except for cohort 5 and cohort 6, and cohort 5 and cohort 8. An increase of 2.27 from cohort 6 to cohort 5, 95% CI [.07, 4.47], was found to be statistically significant, $p = .04$. An increase of 2.34 from cohort 8 to cohort 5, 95% CI [.24, 4.44], was also found to be statistically significant, $p = .02$.

Table 2

*Results from One-way ANOVA Analyses Comparing Pre-service teachers' Pre-TPACK Scores in Nine Cohorts (n = 1,246)*

<table>
<thead>
<tr>
<th>TPACK domains</th>
<th>df</th>
<th>$F$</th>
<th>$p$</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-CK</td>
<td>1237</td>
<td>2.50</td>
<td>.01**</td>
<td>.02</td>
</tr>
<tr>
<td>Pre-PK</td>
<td>1237</td>
<td>.93</td>
<td>.49</td>
<td>.01</td>
</tr>
<tr>
<td>Pre-TK</td>
<td>476.84</td>
<td>3.02</td>
<td>.003**</td>
<td>.02</td>
</tr>
<tr>
<td>Pre-PCK</td>
<td>473.05</td>
<td>1.27</td>
<td>.26</td>
<td>.01</td>
</tr>
<tr>
<td>Pre-TCK</td>
<td>1237</td>
<td>1.82</td>
<td>.07</td>
<td>.02</td>
</tr>
<tr>
<td>Pre-TPK</td>
<td>471.04</td>
<td>2.69</td>
<td>.007**</td>
<td>.02</td>
</tr>
<tr>
<td>Pre-TPACK</td>
<td>1237</td>
<td>2.02</td>
<td>.04*</td>
<td>.01</td>
</tr>
</tbody>
</table>

*Note.* *p < .05; **p < .01; ***p < .001

For pre-TK scores, a statistically significant difference was found, $F(8, 476.84) = 3.02, p = .003, \eta^2 = .02$. Games-Howell tests revealed that there were statistically significant differences between cohort 6 and cohort 2 and between cohort 6 and cohort 3. Pre-service teachers' pre-TK scores increased 1.49 from cohort 6 to cohort 2, 95% CI [.04, 2.93], which was found to be
statistically significant, \( p = .04 \). Similarly, pre-service teachers' pre-TK scores increased 1.95 from cohort 6 to cohort 3, 95% CI [.59, 3.31], which was also found to be statistically significant, \( p < .0005 \).

There was also a statistically significant difference in pre-service teachers' pre-TPK scores, \( F(8, 471.04) = 2.69, \ p = .01, \ \eta^2 = .02 \). Games-Howell tests showed that there were statistically significant differences between cohort 2 and cohort 5, 7, and 9. A decrease of .84 from cohort 2 to cohort 5, 95% CI [-1.66, -.02], was found to be statistically significant, \( p = .04 \). A decrease of 1.02 from cohort 2 to cohort 7, 95% CI [-1.96, -.09], was found to be statistically significant, \( p = .01 \). A decrease of .93 from cohort 2 to cohort 9, 95% CI [-1.81, -.04], was also found to be statistically significant, \( p = .03 \).

Pre-service teachers' pre-TPACK scores were found to be statistically significantly different in the nine cohorts, \( F(8, 1237) = 2.02, \ p = .04, \ \eta^2 = .02 \). Post hoc tests were run to investigate all possible group comparisons. However, no statistically significant difference was detected in any of the post hoc tests.

From the results of the one-way ANOVA tests, it was evident that most pre-service teachers' pre-TPACK scores remained stable over the nine academic years. For the four pre-TPACK domains (CK, TK, TPK, and TPACK), which showed statistically significant differences, the results of the post hoc results revealed that most of the group comparisons were not statistically significant. Furthermore, the effect sizes of these one-way ANOVA tests were rather small (close to zero). The small effect sizes meant that the statistically significant differences detected from the analysis were minimal among the cohorts. Thus, it was logical to consider that the pre-service teachers' pre-TPACK scores in the nine cohorts remained relatively
stable over the nine academic years. A discussion of the possible reasons for the stability of pre-service teachers' pre-TPACK scores will be provided in the discussion section.

Research Question 2: What are pre-service teachers’ clusters based on their pre-TPACK scores?

After running the two-step cluster analyses, a two-cluster model was selected due to its proper fit to the criteria. Thus, pre-service teachers were grouped into these two clusters. Cluster 1 had 600 (48.15%) pre-service teachers, while cluster 2 had 646 (51.85%) pre-service teachers. Concerning the demographic characteristics, the compositions of these two clusters were similar (see Table 3).

Table 3

<table>
<thead>
<tr>
<th>Demographic characteristics</th>
<th>Cluster 1 (n = 600)</th>
<th>Cluster 2 (n = 646)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>541</td>
<td>90.17%</td>
</tr>
<tr>
<td>Male</td>
<td>59</td>
<td>9.83%</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-22</td>
<td>544</td>
<td>90.67%</td>
</tr>
<tr>
<td>23-26</td>
<td>37</td>
<td>6.17%</td>
</tr>
<tr>
<td>27-32</td>
<td>10</td>
<td>1.67%</td>
</tr>
<tr>
<td>32+</td>
<td>9</td>
<td>1.50%</td>
</tr>
<tr>
<td>Year in College</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>126</td>
<td>21.00%</td>
</tr>
<tr>
<td>Sophomore</td>
<td>301</td>
<td>50.17%</td>
</tr>
<tr>
<td>Junior</td>
<td>137</td>
<td>22.83%</td>
</tr>
<tr>
<td>Senior</td>
<td>36</td>
<td>6.00%</td>
</tr>
<tr>
<td>Major</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECE</td>
<td>102</td>
<td>17.00%</td>
</tr>
<tr>
<td>EL ED</td>
<td>46</td>
<td>78.00%</td>
</tr>
<tr>
<td>Other</td>
<td>30</td>
<td>5.00%</td>
</tr>
<tr>
<td>Enrolled in the Learning Technologies Minor</td>
<td>78</td>
<td>13.00%</td>
</tr>
<tr>
<td>Past or current practicum experiences</td>
<td>238</td>
<td>39.67%</td>
</tr>
</tbody>
</table>

Comparing the pre-TPACK scores, pre-service teachers in cluster 2 reported relatively higher scores in all the seven TPACK subscales. Independent sample \( t \)-tests were run to detect
whether there were statistically significant differences in the seven TPACK domains in the two clusters (see Table 4), and statistically significant differences were found in the results.

Table 4

Results from the Independent Sample t-test Comparing Pre-service Teachers' Pre-TPACK Scores in Two Clusters

<table>
<thead>
<tr>
<th>TPACK domains</th>
<th>Cluster 1 (n = 600)</th>
<th>Cluster 2 (n = 646)</th>
<th>Independent sample t-test</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>CK</td>
<td>42.24</td>
<td>5.21</td>
<td>45.76</td>
<td>4.57</td>
</tr>
<tr>
<td>PK</td>
<td>23.75</td>
<td>3.19</td>
<td>28.21</td>
<td>2.89</td>
</tr>
<tr>
<td>TK</td>
<td>19.77</td>
<td>3.74</td>
<td>22.22</td>
<td>3.73</td>
</tr>
<tr>
<td>PCK</td>
<td>12.61</td>
<td>1.97</td>
<td>15.72</td>
<td>1.53</td>
</tr>
<tr>
<td>TCK</td>
<td>11.34</td>
<td>2.63</td>
<td>14.59</td>
<td>2.25</td>
</tr>
<tr>
<td>TPK</td>
<td>17.87</td>
<td>2.42</td>
<td>20.70</td>
<td>1.81</td>
</tr>
<tr>
<td>TPACK</td>
<td>25.01</td>
<td>3.91</td>
<td>31.56</td>
<td>3.02</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.

The results from these tests justified that there were statistically significant differences in all the seven pre-TPACK subscales scores between the two clusters. For CK and TK, there were medium effect sizes of .72 and .66. For PK, PCK, TCK, TPK, and TPACK, there were significant effect sizes of 1.47, 1.76, 1.33, 1.32, and 1.87 respectively. These results offered empirical evidence that the two-cluster model was a good fit in determining two heterogeneous groups that in turn was homogeneous within the groups. Pre-service teachers in cluster 1 reported lower pre-TPACK scores compared to pre-service teachers in cluster 2, who reported higher pre-TPACK scores.

Research Question 3: Do pre-service teachers develop TPACK after taking a required educational technology course?

Pair-sample t-tests were used to investigate the overall effectiveness of the required educational technology course on pre-service teachers’ development of TPACK by comparing
their self-reported pre-TPACK scores to their post-TPACK scores on the TPACK survey.

Statistically significant differences were found in all seven TPACK domains (see Table 5). It was also crucial to look into the effect sizes of these tests. The effect sizes were medium for CK, PK, TK, and PCK, which were .56, .60, .71, and .52, while the effect sizes were large for TPK, TCK, and TPACK, 1.02, .77, and .93 respectfully. These results demonstrated that in general, the required educational technology course was effective in developing pre-service teachers’ TPACK. After taking the course, pre-service teachers reported that they developed TPACK in all seven knowledge domains.

Table 5

Results from the Paired Sample t-test Comparing Pre-service Teachers' Pre-TPACK Scores to Post-TPACK Scores

<table>
<thead>
<tr>
<th>TPACK domains</th>
<th>Prior TPACK (n = 1,246)</th>
<th>Post TPACK (n = 1,246)</th>
<th>Independent sample t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>CK</td>
<td>44.07</td>
<td>5.19</td>
<td>47.00</td>
</tr>
<tr>
<td>PK</td>
<td>26.06</td>
<td>3.77</td>
<td>28.35</td>
</tr>
<tr>
<td>TK</td>
<td>21.04</td>
<td>3.93</td>
<td>23.48</td>
</tr>
<tr>
<td>PCK</td>
<td>14.22</td>
<td>2.35</td>
<td>15.57</td>
</tr>
<tr>
<td>TCK</td>
<td>13.03</td>
<td>2.93</td>
<td>16.29</td>
</tr>
<tr>
<td>TPK</td>
<td>19.33</td>
<td>2.55</td>
<td>21.53</td>
</tr>
<tr>
<td>TPACK</td>
<td>28.41</td>
<td>4.78</td>
<td>33.06</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.

Research Questions 4: Are there differences in pre-service teachers’ post-TPACK and TPACK-development scores according to pre-service teachers’ assignment to clusters based on their pre-TPACK scores?

Independent-sample t-tests were utilized to examine how different clusters of pre-service teachers developed different levels of TPACK after taking the required educational technology course and whether there were differences in post-TPACK scores between the two clusters.
(Cluster 1 – lower pre-TPACK scores, Cluster 2 – higher pre-TPACK scores). There were statistically significant differences in the post-TPACK scores between the two clusters. Overall, pre-service teachers who had higher pre-TPACK scores at the beginning of the course reported higher post-TPACK scores after taking the educational technology course (see Table 6). The effect sizes for these tests were medium, ranging from .39 to .70. These results showed that overall, cluster 2 pre-service teachers who reported higher pre-TPACK scores still had higher post-TPACK scores after completing the course. Cluster 1 pre-service teachers who reported lower pre-TPACK scores, still had statistically significant differences in their post-TPACK scores, but their post-TPACK scores were lower than cluster 2 pre-service teachers.

Table 6

Results from the Independent Sample t-test Comparing Pre-service Teachers' Post-TPACK Scores in the Two Clusters

<table>
<thead>
<tr>
<th>TPACK domains</th>
<th>Cluster 1 ( (n = 600) )</th>
<th>Cluster 2 ( (n = 646) )</th>
<th>Independent sample t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M )</td>
<td>( SD )</td>
<td>( M )</td>
</tr>
<tr>
<td>CK</td>
<td>45.92</td>
<td>5.26</td>
<td>47.99</td>
</tr>
<tr>
<td>PK</td>
<td>27.16</td>
<td>3.34</td>
<td>29.45</td>
</tr>
<tr>
<td>TK</td>
<td>22.84</td>
<td>3.16</td>
<td>24.07</td>
</tr>
<tr>
<td>PCK</td>
<td>14.85</td>
<td>2.21</td>
<td>16.24</td>
</tr>
<tr>
<td>TCK</td>
<td>15.80</td>
<td>2.00</td>
<td>16.75</td>
</tr>
<tr>
<td>TPK</td>
<td>21.00</td>
<td>2.24</td>
<td>22.02</td>
</tr>
<tr>
<td>TPACK</td>
<td>32.03</td>
<td>3.56</td>
<td>34.02</td>
</tr>
</tbody>
</table>

Note. * \( p < .05 \); ** \( p < .01 \); *** \( p < .001 \).

Another set of independent sample t-tests were conducted to measure the differences in pre-service teachers' TPACK-development scores. Overall, pre-service teachers in cluster 1 (lower pre-TPACK scores) reported higher TPACK-development scores than pre-service teachers in cluster 2 (higher pre-TPACK scores) (see Table 7). The effect sizes for CK-
development (.28) and TK-development scores (.36) were small. The effect sizes for PK-development (.59), PCK-development (.69), and TPK-development (.67) were medium. The effect sizes for TCK-development (.76) and TPACK-development (1.02) were large. Results indicated that although cluster 1 pre-service teachers reported higher TPACK-development scores after taking the course, those scores were still not as high as those of pre-service teachers in cluster 2.

Table 7

Results from the Independent Sample t-test Comparing Pre-service teachers' TPACK-Development Scores in the Two Clusters

<table>
<thead>
<tr>
<th>TPACK domains</th>
<th>Cluster 1 (n = 600)</th>
<th>Cluster 2 (n = 646)</th>
<th>Independent sample t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>CK</td>
<td>3.69</td>
<td>5.32</td>
<td>2.23</td>
</tr>
<tr>
<td>PK</td>
<td>3.41</td>
<td>3.70</td>
<td>1.25</td>
</tr>
<tr>
<td>TK</td>
<td>3.08</td>
<td>3.47</td>
<td>1.85</td>
</tr>
<tr>
<td>PCK</td>
<td>2.24</td>
<td>2.67</td>
<td>.53</td>
</tr>
<tr>
<td>TCK</td>
<td>4.46</td>
<td>3.17</td>
<td>2.16</td>
</tr>
<tr>
<td>TPK</td>
<td>3.14</td>
<td>2.93</td>
<td>1.32</td>
</tr>
<tr>
<td>TPACK</td>
<td>7.01</td>
<td>4.92</td>
<td>2.46</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.

Discussion

In this study, several notable findings were discovered. First, pre-service teachers' pre-TPACK scores remained relatively stable over nine academic years. There were no apparent upward or downward trends. Second, a two-cluster model was found to be ideal for grouping pre-service teachers into two distinct clusters based on their pre-TPACK scores. In general, pre-service teachers in cluster 2 had higher pre-TPACK scores compared to pre-service teachers in cluster 1. Third, the required educational technology course was effective in developing pre-
service teachers' TPACK over the years, which justifies the worth of offering this type of course in teacher education programs. Finally, pre-service teachers in cluster 1 reported higher TPACK-development scores compared to those in cluster 2. However, cluster 1 pre-service teachers still had lower post-TPACK scores as compared to cluster 2 pre-service teachers. These findings indicate that cluster 1 pre-service teachers still reported lower post-TPACK than pre-service teachers who reported higher pre-TPACK scores before starting the course. In the following section, a discussion of these findings and some future directions for research and practice are offered.

**The Trend of Pre-TPACK scores in the Nine Pre-service Teachers' Cohorts**

Before conducting the cluster analyses and other parametric analyses, the trend of pre-service teachers’ pre-TPACK scores during nine academic years collected from the TPACK survey was investigated (Schmidt et al., 2009). Results indicated that pre-service teachers' pre-TPACK scores remained relatively stable over the nine academic years. This finding is both unexpected and interesting. Conceptually, most would postulate that pre-service teachers would have higher prior knowledge related to technology over the years as they enter a teacher education program because there were rapid developments in technology from 2008 to 2017. It is intuitive to make this argument because ideally, pre-service teachers would have more technology available to them during their K-12 education and in their personal lives. In turn, they should develop more TK, if not others, over the years. However, the findings reveal that pre-service teachers did not significantly change their pre-TPACK scores over these nine years and the scores remained relatively stable over those years. This result leaves the teacher educators with an important question: why there is a lack of growth in pre-service teachers' pre-TPACK scores? Next, a few possible reasons for this unexpected result are offered.
First, the design of the survey might be a significant reason that a trend was not detected in the pre-TPACK scores. The validated TPACK survey used for this research was designed with the purpose of serving as a measurement tool for the seven TPACK subscales. The design of the survey followed Koehler, Mishra, and Yahya's (2007) original conceptualization of TPACK which states "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" (p. 741). The TPACK framework is a broad and general way of understanding teachers' knowledge. It does not require a particular pedagogical orientation. Instead, guided by this framework, teachers could utilize various pedagogical approaches to develop appropriate, content-specific strategies and representations (Harris & Hofer, 2011). Therefore, when designing the TPACK survey, there were no questions designed to measure particular content area knowledge, educational technology or teaching method. As a result, the questions are general and contain uncertain elements. In turn, pre-service teachers completing the survey need to be self-aware of how they interpret the questions and must strive to make a realistic assessment of their ability (Willermak, 2017). For example, technology is broadly defined and is referred to as the digital tools we use such as computers, laptops, iPods, handhelds, interactive whiteboards, software programs, etc. One question specifically used for measuring TK on the survey is "I know about a lot of different technologies" (Schmidt et al., 2009). This question is both broad and general. Pre-service teachers might interpret the term "technology" as the emerging educational technologies for instruction, or basic productivity software. Similarly, for another question, "I can learn technology easily," students might perceive the term "technology" as emerging technologies, instead of the more transparent
educational technology. Therefore, although what could be considered as emerging technologies changed every year, pre-service teachers might report their perceptions of the TK they possess at the moment and their abilities to learn what they consider to be emerging technologies at that time. Thus, even though pre-service teachers generate different interpretations of the questions at various times, their interpretations do not affect how they rate their ability. Hence, pre-service teachers’ pre-TPACK scores remained relatively stable over the nine year period.

This result also provides some evidence that the TPACK survey is relatively reliable because it has consistently measured the same constructs over the years. Moreover, there are repeated significant results from the survey, and the measures are stable and inherently repeatable (Cozby, 2001). This result also supports that the TPACK framework is a useful conceptual framework to use for measuring pre-service teachers' knowledge domains. This view is contrary to Cox’s (2008) argument that the TPACK framework is a sliding framework, and it will phase out over time. Though particular technologies become widely adopted in the classroom, more emerging educational technologies are being created every year. This rapid growth in the creation and implementation of emerging educational technologies highlights the need for teachers to continue to acquire TK, and correspondingly, TCK, TPK, and TPACK. Therefore, the TPACK framework can contribute to serving as a useful frame and common language for research and practice. More qualitative research that explores how pre-service teachers perceive their development of TK is still needed.

Second, another reason that the pre-service teachers' pre-TPACK scores remained constant over the nine years, especially their CK and PK scores, might be that pre-service teachers have few transformative learning experiences both in the K-12 and higher education settings. It is possible that content (CK), what is taught in K-12 and higher education settings,
does not change dramatically from year to year. Thus, pre-service teachers’ CK remains stable. Moreover, although technological tools are becoming more popular, they might not be integrated into instruction with content-specific pedagogies in transformative ways. A report titled *Teachers’ Use of Educational Technology in U.S. Public Schools: 2009* published by the Institute of Education Statistics found that 95% of classrooms in U.S. public schools have access to computers with Internet Access (Gray, Thomas, & Lewis, 2010). However, only 40% teachers of the reported used technology often in their classroom. For those teachers who reported using technology often, it was unclear whether they were using technology just for substitution, augmentation, and modifications, or for redefinition purposes (Puenteledura, 2006). Thus, pre-service teachers might not have ample instruction and modeling of effective use of technology from their teachers and teacher educators, which in turn, reflect the lack of growth in their reported pre-TPACK scores (Hamilton, Rosenberg, & Akcaoglu, 2016).

For future research, it is essential to examine the trend of pre-service teachers' pre-TPACK using other research methodologies. Qualitative research methods, such as focus group interviews and ethnography, will provide more insights and reveal more in-depth topics worthy of further discussion. Furthermore, several technology-specific TPACK surveys have been developed (e.g., TPCK-W survey, Lee & Tsai, 2010; TPACK for Online Learning survey, Archambault & Barnett, 2010; PT-TPACK survey, Lux, Bangert, & Whittier, 2011; TPACK-P survey, Jen, Yeh, Hsu, Wu, & Chen, 2016; Game-Based TPACK survey, Hsu, Liang, Chai, & Tsai, 2013; The Interactive Whiteboard (IWB) TPACK survey, Jang & Tsai, 2012; Koh & Divaharan, 2013). Comparing the data from these content-specific TPACK surveys to those from the general TPACK surveys (Chai, Koh, & Tsai, 2010; Jamieson-Proctor et al., 2013; Kaya & Dag, 2013; Koh, Chai, & Tsai, 2010; Schmidt et al., 2009) might reveal more details of how pre-service
teachers perceive and self-assess their TPACK. In addition, more conceptual and empirical research is needed to help identify effective instructional strategies for teacher educators and professional development that prepares both K-12 and higher education educators. More instructional materials, online resources, and research findings should be shared nationally and internationally, especially when 1:1 device programs are becoming more prevalent in the United States and all over the world. Teachers will need to develop knowledge around designing and teaching TPACK lessons in 1:1 programs (Hofer & Harris, 2016; Jin & Crawford, 2017).

Pre-service Teachers' Development of TPACK

The purpose of this research was to investigate the cluster assignment of 1,246 pre-service teachers based on their pre-TPACK scores before taking a required educational technology course, and then to examine whether their pre-TPACK scores affected their post-TPACK and TPACK-development scores after taking the course. Findings reported that pre-service teachers fall into two distinct clusters. Pre-service teachers in cluster 1 reported lower scores in all seven TPACK subscales than cluster 2 pre-service teachers. This result implies that pre-service teachers do bring a different amount of prior knowledge and experiences with them as they enter higher education settings. Koh and Chai (2014) found that pre-service teachers fell into two clusters as well. However, unlike Koh and Chai's (2014) study, neither gender nor age was found to be a variable that influenced pre-service teachers' pre-TPACK scores in this study.

In general, statistically significant gains in pre-service teachers' post-TPACK scores were found, which provides empirical evidence that the required educational technology course taught at this institution was consistently effective over nine years. Specifically, this course has remained fairly “rich” in terms of TPACK design and delivery. In 2013, the course underwent a major content redesign. Although it is impossible to tell whether various course designs had a
different impact on pre-service teachers' development of TPACK, it is evident that pre-service teachers need differentiated and content-specific instruction to help develop their TPACK. It might be worth investigating whether there are differences in pre-service teachers’ post-TPACK and TPACK-development scores when both course design and prior knowledge are considered. Thus, exploring how the course design impacts pre-service teachers’ post-TPACK and TPACK-development scores in the two clusters would be worthwhile. In addition, a meta-analysis of published studies on the effects of TPACK instruction is greatly needed to guide and inform teacher educators' practice.

A primary debate exists about whether pre-service teachers develop TPACK for and in practice or do they just develop and report as being more confident in their own TPACK. Some scholars argue that gains in teachers' self-reported knowledge over time mostly reflect their increased confidence rather than their actual increased knowledge in practice (Harris, Grandgenett, & Hofer, 2010; Lawless & Pellegrino, 2007). Results from this study might reflect some pre-service teachers' gains in their confidence in TPACK instead of their actual knowledge gain in their ability to teach with technology. Hence, additional studies are needed that use multiple research and assessment measures to test these assumptions. For example, Agyei and Keengwe (2014) used both self-reported survey data and performance-based assessment data but did not find a correlation between the two measurements.

Even if the assumption were correct that pre-service teachers did not develop knowledge in practice related to technology, the required educational technology course still could be beneficial as a practical approach to develop pre-service teachers' confidence in TPACK. As Niess, Lee, and Sadri (2007) pointed out, there are five stages of how teachers develop TPACK; 1) recognizing, 2) accepting, 3) adapting, 4) exploring, and 5) advancing. The purpose of the
required educational technology course mentioned in this study was to help pre-service teachers recognize and demonstrate an understanding of using technology to support learning and teaching. Although the pre-service teachers in this study might not develop TPACK at all of these stages after taking the course, confidence and positive perceptions toward technology use and integration might motivate them to continue their learning. Longitudinal studies tracking pre-service teachers' development of TPACK during their teacher education program and that incorporate several data sources for data triangulation are needed to understand how pre-service teachers develop their TPACK at these five stages over time (Niess, 2016; Niess, Lee, & Sadri, 2007). This finding also highlights the need for providing pre-service teachers with more opportunities to learn about technology use and integration in methods courses, practicums, and field experiences. A program-wide approach is needed to offer pre-service teachers adequate preparation on technology integration (Niess, 2011, 2016). Moreover, teacher educators should assert a more collaborative effort when designing the educational technology course, content-specific methods courses, and field experiences in the teacher education program (Foulger et al., 2012, 2015). Consistency in a coherent program will be paramount for pre-service teachers to develop adequate TPACK and TPACK strategic thinking (Mishra & Koehler, 2006; Niess, 2011).

Finally, when comparing pre-service teachers’ post-TPACK and TPACK-development scores in the two clusters, pre-service teachers in cluster 1 (lower pre-TPACK scores) reported lower post-TPACK scores and higher TPACK-development scores compared to pre-service teachers in cluster 2 (higher pre-TPACK scores). These findings indicate that the knowledge gap between these two groups is still not closed by just one educational technology course. This may be similar to the Matthew Effect frequently reported in the reading research, in which the rich get
richer and the poor get poorer (Stanovich, 2000). Since the course had a significant redesign in 2013, it may be worthwhile to examine the various designs of the course and investigate whether there are differences in pre-service teachers’ post-TPACK and TPACK-development scores concerning both course design and prior knowledge. More research should be conducted on examining whether pre-service teachers in the two clusters need differentiated instruction when taking the course.

Although a required educational technology course is useful in preparing pre-service teachers for technology use and integration, it is still not enough for fully developing their TPACK and TPACK strategic thinking (Mishra & Koehler, 2006; Niess, 2011). More content-specific preparation and technology-infused field experiences are needed to achieve this goal. More studies that investigate program-wide efforts in curriculum and program redesign are needed. Such research will help not only other teacher education programs begin similar efforts, but will also encourage stakeholders to seek opportunities for collaboration (Buss et al., 2015; Foulger et al., 2012, 2015; Wetzel et al., 2014).

**Limitations**

The purpose of this study was to investigate pre-service teachers’ pre-TPACK scores before taking a required educational technology course and how their pre-TPACK scores impact their post-TPACK and TPACK-development scores after taking the course. A two-step cluster analysis was used as the primary statistical test to enroll pre-service teachers into distinct clusters based on their pre-TPACK scores. However, cluster analysis does have several limitations to consider.

First, guided by the TPACK framework and research studies on prior knowledge, it was assumed that there was some structure among pre-service teachers' prior knowledge. During the
cluster analyses, several different modeling solutions were produced. To select the optimum answer, the researchers conducted a literature review and extensive statistical analysis. For example, to provide validations to the two-cluster model, an independent-sample t-tests were used to examine whether the clusters were distinct from each other. The results of these tests provided evidence that the clusters were meaningful and relevant to the research. Although a two-cluster model was selected and considered to be the best representation of the structure, other alternatives might also be acceptable. Additional replication studies would be welcomed.

Second, cluster analysis is descriptive and noninferential in nature, which means one might not be able to draw inferences from the sample used in this research to a pre-service teachers' population of the United States or other countries. More replication studies are needed to generate models with different samples to find out the ideal models for different contexts. Comparing the models in various contexts would provide insights on the status related to technology use and integration in teacher education programs nationally and internationally and open doors for more discussion and collaboration.

Some might consider using a survey method to accurately measure pre-service teachers' development of TPACK as another limitation of the study (Archambault & Barnett, 2010; Cox & Graham, 2009). As stated by Lawless and Pellegrino in 2007, gains in teachers' self-reported knowledge over time might reflect their increased confidence rather than their actual increased knowledge in practice. Therefore, to confirm pre-service teachers’ membership in the clusters, one survey instrument might not be enough. More in-depth interviews or focus group interviews should be conducted with pre-service teachers.

**Conclusion**

This longitudinal study used multi-year data to investigate whether pre-service teachers
had different pre-TPACK scores before taking the required educational technology course. As a result, pre-service teachers fell into two distinct clusters. Pre-service teachers in cluster 1 reported both lower pre-TPACK and post-TPACK scores compared to pre-service teachers in cluster 2. Therefore, to improve the effectiveness of the required educational technology course, the design of the course might be revisited, with an emphasis on finding strategies that address the learning needs of pre-service teachers with varying degrees of TPACK. Moreover, it is implied from this study’s results that one educational technology course is not enough for developing pre-service teachers' TPACK. It will be imperative for teacher education programs to find and design effective and practical strategies that will prepare pre-service teachers for using technology in learning and teaching. These preparation efforts must be sustained and supported throughout the entire teacher education program.

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CHAPTER 4. IMPACT OF PRIOR KNOWLEDGE AND COURSE DESIGN ON PRE-SERVICE TEACHERS’ TPACK DEVELOPMENT IN A REQUIRED EDUCATIONAL TECHNOLOGY COURSE

Abstract: Prior knowledge, course design, and technology preparation play vital roles in pre-service teachers' development of TPACK. The purpose of this study was to investigate the impact of prior knowledge, course design, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores in a required educational technology course. Two-way multivariate analysis of variance (MANOVA) was run. All three variables affected pre-service teachers' post-TPACK and TPACK-development scores. In particular, cluster 2 pre-service teachers who reported higher pre-TPACK scores, had higher post-TPACK scores compared to the pre-service teachers in cluster 1 (low pre-TPACK scores). The content-specific course design, which integrated the TPACK framework into practice, was more effective for developing pre-service teachers’ TPACK. However, although cluster 1 pre-service teachers (low pre-TPACK scores) reported higher TPACK-development scores than cluster 2 pre-service teachers (high pre-TPACK scores), differences were still found between groups. Results of this study provide empirical evidence that prior knowledge and course design can impact pre-service teachers’ development of TPACK. Future directions for research and practical implications are discussed.

Keywords: TPACK, prior knowledge, course design, technology preparation, pre-service teachers, ANOVA tests
Introduction

It is a consensus among teacher educators that developing pre-service teachers' technological pedagogical content knowledge (TPACK) (Mishra & Koehler, 2006) and preparing them to use TPACK strategic thinking (Niess, 2011, 2016) in practice are quite challenging (Tondeur, van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012). A significant number of research studies have been conducted to measure pre-service teachers' development of TPACK in teacher education programs (Tondeur et al., 2012; Willermark, 2017). For some, positive outcomes have occurred from the adoption of various strategies examined (Duffield & Moore, 2006; Mims, Polly, Shepherd, & Inan, 2006; Willermark, 2017). While other researchers revealed that graduates of teacher education programs report feeling unprepared to integrate technology into their instruction (Gray, Thomas, & Lewis, 2010; Kay, 2006; Kleiner, Thomas, & Lewis, 2007; Lambert, Gong, & Cuper, 2008; Smarkola, 2007; Yali, 2007). This troublesome finding warrants more research efforts for examining how pre-service develop TPACK (Mishra & Koehler, 2006) and TPACK strategic thinking (Niess, 2011, 2016) during various stages of their teacher education programs.

In most teacher education programs, a stand-alone educational technology course is the first place where pre-service teachers learn about technology integration. A significant amount of studies have been conducted in such courses (Willermark, 2017). Findings from these studies pinpointed the effectiveness of such a course in developing pre-service teachers' TPACK domains (Abbitt, 2011; Bai & Ertmer, 2008; Graham, Borup, & Smith, 2012; Schmidt et al., 2009). However, pre-service teachers commented that they needed more preparation in addition to this course (Buss, Wetzel, Foulger, & Lindsey, 2015; Foulger, Buss, Wetzel, & Lindsey, 2012; Koh & Divaharan, 2011). Most studies did not provide detailed descriptions of how the
educational technology courses were designed and certainly did not use the course design as a variable to examine its impact on pre-service teachers' development of TPACK. Thus, it becomes necessary to investigate how to fully utilize the design of such a course to maximize pre-service teachers' learning outcomes. It is also necessary to think about how to align the design of such a course with the methodology courses, field experiences, practicums, and student teaching offered later in teacher education program to continue such preparation for technology integration. The purpose of this study was to investigate whether different course designs impact pre-service teachers' post-TPACK and TPACK-development scores, focusing on both pre-service teachers’ prior knowledge and technology preparation.

**Theoretical and Conceptual Frameworks**

The theoretical and conceptual frameworks undergirding this research are discussed in this section. Constructivism and constructionism are summarized and used as the learning theories guiding this work. The TPACK framework serves as a conceptual framework to conceptualize the knowledge domains pre-service teachers must develop for meaningful technology integration. The TPACK framework offers a common language to effectively communicate the findings of this research.

**Constructivism and Constructionism**

Constructivism is an epistemological theory that proposes the existence of the subjective reality and that knowledge may be constructed by learners either individually or socially (Mills, Bonner, & Francis, 2006). Constructivism states that people continually construct knowledge inside their mind, and this process is influenced by learner's previous experiences and interactions with people and things (O’Donnell, 2012). Constructivist educators believe that knowledge is not transmitted from the teacher to the students. Instead, students are active
learners who construct their own knowledge as they communicate and interact with their environment (Tangdhanakanond, Pitiyanuwat, & Archwame, 2006). Consequently, constructivist educators seek to provide students active learning opportunities to explore, question, integrate, and reconstruct their knowledge. Years after the initial conceptualization of constructivism, technology became a critical part of people’s daily life and education. Consequently, Seymour Papert, a student of Jean Piaget, advanced Piaget’s constructivism and postulated the theory of constructionism for conceptualizing how people learn in a technology-infused environment.

Constructionism was developed to reflect how people learn with the widespread use of technology. Another primary purpose of constructionism was to place more emphasis on the art of learning, such as learning-by-design, problem-based learning, project-based learning, and connected learning (Papert & Harel, 1991). As a result, constructionism emerged from the work of Seymour Papert and his colleagues (Hay & Barab, 2001). Constructionism argues that people construct knowledge by manipulating objects and creating projects (Papert, 1980). This learning-by-making approach facilitates the understanding of "how ideas get formed and transformed when expressed through different media, when actualized in particular contexts, when worked out by individual minds" (Ackermann, 2001, p. 441). Papert (1993) commented that in constructionism, knowledge could be regarded as an uninterrupted and undivided sea of information for people to access when needed. In practice, educators who adopt the constructionism view provide topics, materials, and time for students to embark on their individualized projects. Such educators also endeavor to meaningfully integrate technology into their instruction, emphasizing its affordances for students to tinker and create. In a constructionist learning environment, students work on self-directed projects alone or in teams.
and determine the pace and direction of their learning to reach the learning goals set by themselves (Barr, 1995; Tangdhanakanond et al., 2006).

**The TPACK Framework**

In 1986, Schulman created a coherent theoretical framework to help understand the knowledge teachers need for the teaching. To conceptualize this knowledge, he presented the pedagogical content knowledge (PCK) framework, which includes content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK). Moreover, he drew particular attention to the significance of PCK in the framework.

After the initial conceptualization of the PCK framework, education went through a rapid paradigm shift in which technology integration became more and more prevalent in the classrooms, and new literacies skills became a must-have for 21st-century students (Lankshear & Knobel, 2011). This rapid paradigm shift in education calls for a new conceptual framework to help guide researchers and educators in thinking about the knowledge teachers need for teaching in today’s classroom. Built on Shulman's (1986) PCK framework, the Technological Pedagogical Content Knowledge (TPCK) framework was developed with the hope of offering a conceptual framework to guide research and practice in education, especially teaching with technology (Angeli & Valanides, 2005; Hughes, 2005; Keating & Evans, 2001; Koehler & Mishra, 2005a, 2005b; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys & Marx, 2002; Niess, 2005; Pierson, 2001; Zhao & Frank, 2003). Among these scholars, Mishra and Koehler (2006) were the first to conceptualize the TPCK framework with clarity and discuss in-depth the definitions of seven TPCK knowledge domains (see Figure 1). In 2007, TPCK was renamed to TPACK, which has a connotation of being the "Total PACKage" (Thompson & Mishra, 2007, p. 38). Koehler, Mishra, and Yahya (2007) emphasized the crucial role of TPACK in teaching by
stating that "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" (p. 741). The TPACK framework is both a general and broad conceptual framework, which encourages using various pedagogical approaches for teaching and learning (Harris & Hofer, 2011).

Figure 1. The TPACK framework. Reproduced by permission of the publisher, © 2012 by tpack.org.

The TPACK framework has become widely accepted in the field of education. Furthermore, it undergirds the investigations of the teachers' knowledge needed for technology integration and guides research on the effectiveness of teacher preparation and professional development. Over the last ten years, TPACK scholars developed three distinct perspectives on TPACK (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). First, the TPACK framework is viewed as a natural extension of Shulman's (1986, 1987) PCK framework (Cox &
Graham, 2009; Niess, 2005). Second, Angeli and Valanides (2009) argue that TPCK is a unique body of knowledge evidenced in their research studies conducted over the years (Angeli, 2005; Angeli & Valanides, 2005, 2009; Valanides & Angeli, 2006, 2008a, 2008b). Finally, Mishra and Koehler (2006, 2009) suggest that TPACK is integrative and is built on the interactions of other domains within the context.

**Literature Review**

Since technology has become more and more readily available in the schools, it is the expectation that teachers should be able to integrate technology meaningfully into their daily instruction. Furthermore, as technology use increases in schools, it highlights the necessity of equipping pre-service teachers with the knowledge and skills to teach 21st-century students (Jonassen, 2003). However, less than one-third of pre-service teachers feel prepared for meaningful technology integration after being trained in teacher education programs (National Education Association, 2008). Most pre-service teachers exiting teacher education programs lack the confidence for infusing technology into their curricula (Doering, Hughes, & Huffman, 2003; Gray, Thoas, & Lewis, 2010; Kay, 2006; Kleiner et al., 2007, Lambert, Gong, & Cuper, 2009; National Education Association, 2008; Smarkola, 2007; Yali, 2007). Brown and Warschauer (2006) revealed that technology integration has a peripheral role in most teacher education programs. They also found that pre-service teachers have insufficient exposure to the modeling that is required for effective technology integration. To address these challenges, it has been suggested to invest more time and effort in developing pre-service teachers' technological pedagogical content knowledge (TPACK) in teacher education programs (Mishra & Koehler, 2006). It is important to examine how teacher education programs prepare pre-service teachers for technology integration. An investigation into the studies conducted on measuring pre-service
teachers’ development of TPACK will also shed light on this issue. Accordingly, a literature review on these topics follows.

**Strategies for Preparing Pre-service Teachers for Technology Integration**

Undoubtedly, teacher education programs bear the responsibility of preparing pre-service teachers for technology integration. A considerable amount of effort was put into facilitating pre-service teachers’ technology preparation during the 1990s because of the PT3 grants awarded by the U.S. Department of Education (Hofer, 2005; Moursund & Bielefeldt, 1999; Persichitte, Caffarella, & Tharp, 1997; U. S. Department of Education, 2005, 2009). Scholars who examined the impacts of the PT3 grants found that more pre-service teachers reported feeling prepared for technology integration after these national and collective efforts (Mims et al., 2006). Specifically, teacher education programs were actively seeking strategies for technology integration efforts with consideration of their specific contexts. Three effective strategies emerged from this work and included professional development, collaboration for curriculum reform, and incentives (Duffield and Moore, 2006). Furthermore, Kay (2006) summarized 10 approaches in an extensive review of the literature that are key to teacher preparation with technology, 1) delivering a single technology course, 2) offering mini-workshops, 3) integrating technology in all courses, 4) modeling how to use technology; using multimedia, 5) collaboration among preservice teachers, 6) mentor teachers and faculty, 7) practicing technology in the field, 8) focusing on education faculty, 9) focusing on mentor teachers, and 10) improving access to software, hardware, and/or support (p. 383).

In 2007, the National Center for Educational Statistics (NCES) investigated the strategies teacher education programs use for technology preparation. The report stated that 100% of teacher education programs teach the use of Internet resources and communication tools for
instruction. About 99% taught developing curriculum plans with technology to address content standard. Approximately 97% reported using content-specific software for instruction. In addition, 95% of the programs utilized multimedia digital content for instruction, and 90% used technology to access or manipulate data to guide instruction. Furthermore, 88% reported teaching pre-service teachers how to apply technology in assessing student achievement according to state curriculum standards; 82% taught how to create and use digital portfolios for alternative assessment, and 79% taught the use of student assessment and evaluation strategies. This report did not investigate the depth and quality of these strategies, as well as whether pre-service teachers felt prepared to integrate technology into their curricula upon graduation.

Still, after many of these efforts, pre-service teachers feel unprepared for integrating technology into their classrooms. Recently, the U.S. Department of Education (2017) released an updated 2017 National Education Technology Plan, *Reimagining the role of technology in education: 2017 National Education Technology Plan Update*, and called for the field to re-conceptualize technology integration. As is documented with this national policy, there is still a significant need to investigate how pre-service teachers develop TPACK during their teacher education programs, as well as the effectiveness of the strategies used to advance their TPACK. This warrants a closer examination of the methods teacher education programs use with pre-service teachers to prepare them for technology integration in classrooms.

**Methods for Preparing Pre-service Teachers for Technology Integration**

Three primary methods for preparing pre-service teachers for technology integration are typically used in teacher education programs: 1) stand-alone educational technology course, 2) technology-infused methodology courses, and 3) field experiences with technology integration components (Strudler, Archambault, Bendixen, Anderson, & Weiss, 2003). To conceptualize the
depth and breadth of these methods, it would be beneficial to place these three approaches on a continuum postulated by Beck and Wynn (1998). Stand-alone educational technology courses could be placed at the left end of the continuum. In contrast, a technology-infused teacher education program, which uses a combination of all three approaches, resides at the right end of the continuum. Everything else could be placed in between (Duhaney, 2001). In 2007, when the National Center for Educational Statistics (NCES) surveyed 1,439 teacher education programs, they reported that 79% of the teacher education programs taught technology integration within field experiences, 71% within methodology courses, 51% offered 3- or 4-credit stand-alone educational technology courses, and 34% offered 1- or 2-credit stand-alone educational technology courses (Kleiner et al., 2007).

Although these approaches are transformative and have considerable benefits, in practice, teacher education programs still face barriers in adopting these effective approaches (Goktas, Yildirim, & Yildirim, 2008). Such obstacles include but are not limited to: technology planning and leadership (Tondeur et al., 2012), lack of administrative support (Schoep, 2004), lack of funding (Mehlinger & Powers, 2002), lack of training (Franklin, 2007), insufficient curriculum time (Kleiner et al., 2007), limited time for planning (Chai, Koh, & Tsai, 2013), examination constraints (Harris & Hofer, 2011), training staff (Tondeur et al., 2012), access to resources (Nicholas & Ng, 2012), and uneven technology knowledge among teacher educators (Tondeur et al., 2012). Because of these barriers, most teacher education programs resort to the method of offering a stand-alone educational technology course (Gronseth et al., 2009; Honawar, 2008; Polly, Mims, Shepherds, & Inan, 2010; O’Bannon & Pluckett, 2007; Wentworth, Graham, & Tripp, 2008). Researchers conducted a significant number of studies on the effectiveness of a stand-alone educational technology course. Some positive outcomes were discovered such as
developing pre-service teachers’ TPACK and promoting collaboration among peers (Tondeur et al., 2012; Willermark, 2017). Despite the positives, most believe that a stand-alone educational technology course is not enough for providing pre-service teachers with adequate technology preparation (Bai & Ertmer, 2008; Brown & Warschauer, 2006; Gunter, 2001).

Some teacher education programs sought other approaches like integrating technology into methodology courses and field experiences (Brupbacher & Wilson, 2009; Dexter, Doering, & Riedel, 2006; Niess, 2005; Wetzel, Foulger, Buss, & Lindsey, 2014). Niess (2005) created and evaluated a technology-infused math and science teacher education program. Wetzel et al. (2014) documented efforts of eliminating the stand-alone educational technology course and infusing technology into the methodology courses. These program-wide strategies are found to be more cognitively and developmentally appropriate for pre-service teachers to develop TPACK and TPACK strategic thinking over time (Pierson & Thompson, 2005; Tondeur et al., 2012). However, this program-wide transformation requires a considerable investment of time, resources, leadership, and professional development. Although some pioneering programs have begun this transformation process, unsurprisingly, most teacher education programs still rely on the stand-alone educational technology course. It still seems relevant to examine how teacher educators could design the stand-alone educational technology course to maximize the learning outcomes and lay foundational knowledge for content methodology courses and field experiences. Research conducted specifically on pre-service teachers' development of TPACK follows.

**Research on Pre-service Teachers' Development of TPACK**

It is not an easy task to infuse technology into all courses within a teacher education program due to the lack of the preparation of teacher educators, limited time and resources, and
lack of support from the program or institution (Foulger, Buss, Wetzel, & Lindsey, 2015). Thus, in practice, a stand-alone educational technology course is still a critical component for developing pre-service teachers' TPACK in many teacher education programs (Gronseth et al., 2010; Kleiner et al., 2007). Research studies examining pre-service teachers self-reported TPACK are worth investigating (Tondeur et al., 2012; Willermark, 2017).

Using a pre- and post-survey design, Schmidt et al. (2009) discovered that pre-service teachers developed all seven TPACK domains after taking a stand-alone educational technology course. Specifically, pre-service teachers had more development in TK, TCK, and TPACK. These findings point to the possible effectiveness of a stand-alone educational technology course, as pre-service teachers can develop foundational TPACK in such courses. According to Willermark (2017), at least 26 journal articles were published that applied the TPACK survey developed by Schmidt et al. (2009). Other scholars have adapted this survey according to their contexts and used them in assessing different populations of pre-service teachers' development of TPACK (e.g., Chai, Koh, & Tsai, 2010; Kaya & Dag, 2013; Koh, Chai, & Tsai, 2010; Sahin, 2011). Positive impacts of stand-alone educational technology courses for developing pre-service teachers' TPACK are found in most studies (e.g., Bai & Ertmer, 2008; Foulger et al., 2012).

Qualitative methodologies are also used by TPACK scholars. Koh and Divaharan (2011) developed the TPACK-Developing Instructional Model as an instructional process of developing pre-service teachers' TPACK during the instruction of Information and Communication Technology (ICT) tools. They examined 74 pre-service teachers' development of TPACK by analyzing the qualitative data collected from their course reflections. They found that pre-service teachers develop TK and TPACK. However, the evidence of the development of TPACK was hard to find. To develop their TCK and TPACK, the authors recommended placing more
emphasis on subject-focused pedagogical modeling, product critique, and peer sharing. Meanwhile, Graham, Borup, and Smith (2012) used pre- and post-treatment assessments to measure 133 pre-service teacher's development of TPACK in a stand-alone educational technology course. They found that at the beginning of the course, pre-service teachers' demonstrations of the TPACK domains are limited both in quantity and quality. However, as the course progressed, more demonstrations were identified. Both quantity and quality increased as well, especially for TPK and TPACK.

Findings from most of these studies indicated that pre-service teachers' CK and PK are not fully developed in a stand-alone educational technology course, which in turn, inhibits the development of other knowledge domains (Pamuk, 2011). The most efficient way to bring immediate results is to carefully examine the design of these stand-alone educational technology courses and redesign them to address the discrepancies mentioned above. However, most research studies that investigated pre-service teachers' development of TPACK in a stand-alone educational technology course did not fully describe their course designs (Chai et al., 2010; Koh & Divaharan, 2011; Pamuk, 2011). Therefore, it is difficult to know whether pre-service teachers are taught explicitly about how to align content, pedagogy, and technology in the act of teaching during such courses (Angeli & Valanides, 2005; Mishra & Koehler, 2006). With this context in mind, comparing different course designs of the stand-alone educational technology course might shed light on whether different designs produce different results with respect to pre-service teachers' development of TPACK. It also has practical implications for practice as utilizing the best practices from effective course designs may maximize pre-service teachers' learning outcomes, which ultimately transfer into pre-service teachers’ development of TPACK. Thus, the purpose of this study was to compare the impact of two different course designs of a
stand-alone educational technology course on pre-service teachers' post-TPACK and TPACK-development scores, focusing on pre-service teachers' prior knowledge and technology preparation. Two specific research questions were investigated:

1. To what extent do different course designs of a required educational technology course impact pre-service teachers' post-TPACK and TPACK-development scores?
2. What differences are found, if any, between pre-service teachers' post-TPACK and TPACK-development scores based on their reported pre-TPACK scores?

**Methodology**

In the methodology section, the research context, especially the course designs of the required educational technology course, will be discussed. In addition, detailed information on the survey instrument, data collection, participants, and data analysis are provided.

**Research Context**

Data were collected from the pre-service teachers enrolled in a required educational technology course in a teacher education program at a large Midwestern land-grant university. As pre-service teachers seeking teacher licensure, they need to fulfill four steps: 1) admission to the teacher education program, 2) curriculum and clinical experience, 3) student teaching, and 4) teacher licensure. The required educational technology course in this program is a 3-credit course. Pre-service teachers typically enroll in this course when they are applying to the teacher education program or have just been accepted into the program. This course serves as a foundational course, which orients pre-service teachers into the study of teaching and learning.

A group of instructors forms the instructional team. A tenured faculty member in instructional technology serves as the lead instructor and offers two 50-minute lectures every week, while several lab instructors (i.e., graduate students, instructors, etc.) facilitate one 2-hour
weekly lab section. To fulfill the course requirements, pre-service teachers are expected to attend every lecture and lab and to complete all major course assessments, which are hands-on projects, reflection papers, a technology-infused lesson plan, and an online course portfolio with an accompanying final reflection paper.

A document analysis was conducted on the 18 syllabi used from Fall 2008 to Spring 2017 (Weber, 1990). The purpose of a document analysis is to gain insight into the design and content included, as well as to examine the trends, patterns, and consistency over the nine years. The results of this analysis are in the next section.

**Course Design**

The required educational technology course is designed primarily for pre-service teachers majoring in early childhood education or elementary education, and its purpose is to prepare them to teach with, not about, educational technologies in PK-6 classrooms. The goal is to examine how technology can impact learning and how it can be used to solve instructional problems in classrooms. After taking this course, pre-service teachers should develop an understanding of technology's role in teaching and learning. In general, the course is designed under the instructional framework of the ISTE Standards for Teachers developed by the International Society for Technology in Education (ISTE), which consists of five core standards (ISTE, 1998). These standards defined the fundamental concepts, knowledge, skills, and attitudes pre-service teachers should have when using technology in educational settings. Moreover, they serve as initial learning outcomes and performance indicators of the course.

The lead instructor has taught this course for nearly twenty years. Over the nine years included in this study, the instructional team has attempted to continuously improve the course content to reflect the development and evolution of technology in education.
analysis, it was discovered that most changes in the course focused on adding particular emerging technologies while deleting out-dated technologies. Technologies that were replaced either became transparent in classrooms or became obsolete and were no longer available to teachers and students. For example, creating a podcast was an assignment in the course before 2015, and later on, with changing technology, it was deleted as a course project. A specific lab focusing on using an interactive whiteboard was added in 2011 due to its popularity in K-12 classrooms. Over time, less class time was used learning about IWB and more time was spent on learning about iPad apps in content area curriculum. Google apps were added to the course in 2013 because of their affordances and growing popularity, especially as local school districts began to adopt 1:1 device initiatives. Even though changes were made in teaching various educational technologies, the major assignment for the class did not transform. Over the nine academic years, the primary course assignments remained the same. The major assignments were a technology-infused lesson plan, course portfolio, digital storytelling project, reflection papers, lab projects, in-lecture assignments, and exams.

A major redesign occurred in 2013. The researcher of this study was a lab instructor for the course before the redesign, participated in the course redesign, and taught the course using the new design. The course designs are explained in more details below.

General Course Design. From 2008 to 2013, the required educational technology course was designed around and emphasized the core topics in educational technology and introduced technology tools that were popular in PK-6 classrooms. In lectures, the lead instructor covered specific topics related to educational technology. Information was provided for topics such as information literacy, visual literacy, desktop publishing, technology use in schools, digital images in the classroom, lesson planning for technology integration, copyright, Google apps,
podcasting, digital storytelling, digital video, assessment, spreadsheets, virtual schooling, social networking, digital divide, and the TPACK framework. Corresponding to the topics introduced in the lectures, lab sessions were designed to bridge the theory and practice by offering pre-service teachers the opportunities to work on hands-on technology projects. For example, pre-service teachers created a digital storytelling project in the lab when that topic was presented in lecture.

**Content-Specific Course Design.** In 2013, curriculum mapping and development at program level were conducted. Guided by the TPACK framework, the instructors recognized the importance of aligning technology integration with the content of the subject matter and pedagogical strategies. Therefore, a decision was made to redesign the course to align it with the content of the subject area methodology courses taught within the program. These courses include literacy, science, math, and social studies. As a result, the first iteration of the newly redesigned course was offered in Fall 2014.

The instructional team followed the guidelines of the Backward Design Model (Wiggins & McTighe, 2005) to redesign the course. The Backward Design Model encourages educators to begin with identifying the desired results and then determining the acceptable evidence before planning the learning experiences and instruction. Using this model, the instructional team first consulted the literature on preparing pre-service teachers for technology integration to identify possible desired results for the course. The four principles proposed by Hughes (2005) were chosen to serve as the benchmarks for the course: 1) connecting technology learning to professional knowledge, 2) privileging subject matter and pedagogical content connections, 3) using technology learning to challenge professional knowledge, and 4) teaching many technologies. Three goals were outlined: 1) emphasizing how technology could impact learning
in different subject areas, 2) showcasing how to integrate technology into subject areas, and 3) demonstrating how technology could be used to solve instructional problems in various subject areas in the PK-6 classrooms. Then, the course was structured into five instructional modules, module 1. Introduction to Digital Learning - Building a Foundation, module 2. Technology Integration in Math, module 3. Technology Integration in Literacy, module 4. Technology Integration in Science, and module 5. Technology Integration in Social Studies. Finally, the instructors categorized and ordered the content in each module. For this step, in particular, they consulted the five stages of how teachers develop TPACK (Niess, Lee, & Sadri, 2007). A brief introduction for each module follows.

**Module 1. Introduction to digital learning – building a foundation.** The redesigned course begins with a module focusing on foundational topics related to educational technology. Two critical frameworks are introduced to orient pre-service teachers to think about technology integration in PK-6 classrooms. First, the lead instructor shares the TPACK framework (Mishra & Koehler, 2006) and asks pre-service teachers to reflect on the knowledge they need to have for meaningful technology integration. Then, she introduces Grounded Technology Integration pedagogical model (Harris & Hofer, 2009) for thinking about how to design technology-infused lessons. These models serve as the building blocks for pre-service teachers to use to formulate their understanding of technology integration. Discussion on topics such as being a reflective teacher, information literacy, website evaluation, digital images, copyright and fair use are included. In the lab sections, pre-service teachers complete hands-on projects covering information literacy, Google tools, and digital images. They also learn how to create a course portfolio to document their teaching philosophies and reflect on their teaching and learning processes around technology.
Module 2. Technology integration in math. The importance of math is self-evident, as well as the importance of infusing technology into math instruction (Tondeur, van Braak, Siddiq, & Scherer, 2016; Wachira & Keengwe, 2011). In this module, the lead instructor introduced strategies for integrating technology into the math curricula and showcases useful technological tools, such as Scratch, Explain Everything, and spreadsheets. She also guides the pre-service teachers through the steps of planning for a TPACK lesson using the Backward Design Model (Wiggins & McTighe, 2005). To help pre-service teachers design their TPACK lessons, the instructors share the Mathematics Activity Types (Grandgenett, Harris, & Hofer, 2009). In lab, pre-service teachers work on creating computing and coding projects using Scratch and Scratch Jr. A second lab is used to create a short math lesson for grades 3-6 using Explain Everything. In addition, pre-service teachers also explore and evaluate math iPad apps.

Module 3. Technology integration in literacy. Literacy is the learning foundation for many PK-6 classrooms. Pre-service teachers need to be prepared to teach both traditional literacy and New Literacies (Lankshear & Knobel, 2011). An online, flipped classroom module was designed to showcase the potential of this pedagogical model and various literacy concepts covered in a typical methodology course. Selected readings, resources, and instructional videos were posted on the online module, which introduced some content, pedagogy, and technology tools for literacy instruction in PK-6 classrooms. Additional lectures encourage pre-service teachers to use the K-6 Literacy Activity Types as they think about designing their own lessons (Schmidt, Harris, & Hofer, 2011). In lab, pre-service teachers create their digital storytelling projects, as well as explore and evaluate educational technologies for literacy.

Module 4. Technology integration in science. For this module, the lead instructor first requires the pre-service teachers to examine the Next Generation Science Standards for the
science subject area identification. Pre-service teachers explore what topics they will need to teach in their future classrooms. The lead instructor also introduces the pre-service teachers to a pedagogical approach called the 5E Model of Instruction (Bybee et al., 2006). Lab sessions are designed to reflect the procedures of exploring, explaining, elaborating, and evaluating when using the 5E Model of Instruction. Preservice teachers create interactive science images and videos in labs. They also learn about makerspaces and various technologies used in such a space. Pre-service teachers also participate in a “science” Breakout EDU to experience the power of an immersive learning game. They also explore and evaluate iPad apps designed for the science subject area.

Module 5. Technology integration in social studies. Hammond and Manfra (2009) proposed giving, prompting, and making as a guiding framework that teachers could use to integrate technology into the social studies subject area. In lectures, the lead instructor provides examples of technology integration in the social studies classrooms and prompts pre-service teachers to reflect upon technology use specifically in these three groups. The lead instructor also discusses social media and related Web 2.0 tools that can be integrated into classrooms. In lab, pre-service teachers create movie or book trailers for particular historical events or historical non-fiction books. Like the other subject areas, they are given time to explore several social studies iPad apps.

Survey Instrument and Data Collection

A validated survey called Survey of Pre-service Teachers' Knowledge of Teaching and Technology (Schmidt et al., 2009) was used in this study. Guided by the TPACK framework, this survey is specifically designed to measure the seven TPACK domains of pre-service teachers who major in either early childhood education or elementary education. This survey
consists of eight demographic questions and 46 five-point Likert scale questions (1 = strongly disagree – 5 = strongly agree). Eight questions gather demographic information, twelve questions address CK, seven questions address PK, six questions address TK, four questions address PCK, four questions address TCK, five questions address TPK, and eight questions address TPACK. The internal reliability (coefficient alpha) of the seven TPACK subscales ranged from .75 to .92 (Schmidt et al., 2009).

A pre- and post-survey design was used to collect data from 1,246 pre-service teachers enrolled in the required educational technology course over a period of nine academic years. During the first week of every Fall and Spring semester, an explanation of the research purpose and a link to the pre-survey was offered to the pre-service teachers. Pre-service teachers who voluntarily agreed to participate in the study accessed a link to the survey online. An informed consent form that included details about the study, the purpose and researchers’ contact information was provided to participants. The survey took about 15 to 20 minutes to complete. A similar procedure was used to collect post-survey data. Post-survey data were collected in lab during the last week of the course. This study included the survey results from eighteen academic semesters, nine Fall semesters and nine Spring semesters. For data analysis, these data were aggregated into one dataset.

**Participants**

Over the nine academic years, 1,246 participants completed both pre- and post-TPACK surveys. The majority of the pre-service teachers (974, 78.17%) were elementary education majors, while 222 (17.82%) majored in early childhood education and a few (50, 4.01%) were in other majors. Nearly 90% of the pre-service teachers (1,115, 89.49%) were female, and the rest were male (131, 10.51%). Most participants were 18 to 22 years old (1,139, 91.41%), while a
few (76, 6.10%) were between 23-26 years old. The remaining students (18, 14.00%) were 27-32 years old, and only 13 (1.04%) were 32 years or older. Most pre-service teachers were classified as freshmen (267, 21.43%) and sophomores (591, 47.43%). The remaining participants were juniors (309, 24.80%) and seniors (79, 6.34%). Less than half of the pre-service teachers (503, 40.37%) had some type of practicum experience, while 59.63% of them (743) did not have any prior practicum experience. One hundred forty-six (11.72%) pre-service teachers were enrolled in the Learning Technologies Minor, which provided additional technology courses (16 credits) to help develop pre-service teachers' TPACK.

Since this study focused on investigating the effects of participants’ prior knowledge and course design on pre-service teachers' post-TPACK and TPACK-development scores, these 1,246 pre-service teachers were placed into four distinct groups. Two categorical variables were used to group these pre-service teachers. The first categorical variable was course design. There were two designs over the nine years, the general course design and content-specific course design. The second categorical variable was prior knowledge. In another study using the same data set, cluster analysis was conducted to group pre-service teachers based on their pre-TPACK scores. A two-cluster model was found to be the best fit. Cluster 1 pre-service teachers reported lower pre-TPACK scores compared to cluster 2 pre-service teachers. The cluster membership from this previous study was used in this study as the second categorical variable. Group 1 included 424 pre-service teachers who had low pre-TPACK scores and were enrolled in the course when using the general course design. Group 2 consisted of 459 pre-service teachers with high pre-TPACK scores while taking the course with the general course design. Group 3 included 176 pre-service teachers with low pre-TPACK scores, while Group 4 had 187 pre-service teachers with high pre-TPACK scores. Participants in both of these groups (3 and 4) were
enrolled in the content-specific course design. Table 1 provides a summary of participants’ demographic information.

### Table 1

**Pre-service Teachers' Demographic Characteristics (n = 1,246)**

<table>
<thead>
<tr>
<th>Demographic characteristics</th>
<th>Pre-service teachers' groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (n = 424)</td>
</tr>
<tr>
<td></td>
<td>n (%)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>383 (90.30%)</td>
</tr>
<tr>
<td>Male</td>
<td>41 (9.70%)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>18-22</td>
<td>378 (89.20%)</td>
</tr>
<tr>
<td>23-26</td>
<td>31 (7.30%)</td>
</tr>
<tr>
<td>27-32</td>
<td>10 (2.40%)</td>
</tr>
<tr>
<td>32+</td>
<td>5 (1.20%)</td>
</tr>
<tr>
<td>Year in college</td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>85 (20.00%)</td>
</tr>
<tr>
<td>Sophomore</td>
<td>207 (48.80%)</td>
</tr>
<tr>
<td>Junior</td>
<td>99 (23.30%)</td>
</tr>
<tr>
<td>Senior</td>
<td>33 (7.80%)</td>
</tr>
<tr>
<td>Major</td>
<td></td>
</tr>
<tr>
<td>ECE</td>
<td>85 (20.00%)</td>
</tr>
<tr>
<td>EL ED</td>
<td>316 (74.50%)</td>
</tr>
<tr>
<td>Other</td>
<td>23 (5.40%)</td>
</tr>
<tr>
<td>Enrolled in the learning</td>
<td>46 (10.80%)</td>
</tr>
<tr>
<td>technologies minor</td>
<td></td>
</tr>
<tr>
<td>Past or current practicum</td>
<td>138 (32.50%)</td>
</tr>
<tr>
<td>experiences</td>
<td></td>
</tr>
</tbody>
</table>
Data Analysis

An essential pre-requisite for data analysis was that the TPACK survey used for the study was reliable. Therefore, the internal consistency reliability of each survey scale for the seven TPACK domains was examined. Cronbach's coefficient alphas (\(\alpha\)) were computed. For the pre-survey, the Cronbach's coefficient alphas (\(\alpha\)) ranged from .80 to .92 (i.e., TK: \(\alpha = .86\); CK: \(\alpha = .80\); PK: \(\alpha = .87\); PCK: \(\alpha = .83\); TCK: \(\alpha = .87\); TPK: \(\alpha = .82\); TPACK: \(\alpha = .92\)). Similar results were found for the Cronbach's coefficient alphas (\(\alpha\)) of the post-survey, ranging from .86 to .91 (i.e., TK: \(\alpha = .86\); CK: \(\alpha = .86\); PK: \(\alpha = .91\); PCK: \(\alpha = .86\); TCK: \(\alpha = .87\); TPK: \(\alpha = .88\); TPACK: \(\alpha = .91\)). The survey scales were considered decent for measuring what they intended to for applied scenarios under the guideline cited by Nunnaly and Berstein (1994). A Cronbach's alpha (\(\alpha\)) of .70 is considered acceptable for exploratory studies, .80 for basic research, and .90 for applied scenarios (George & Mallory, 2003; Lance, Butts, & Michels, 2006). The TPACK survey used in this study was found to be both valid and reliable. Thus, it was used to collect data with the purpose for measuring pre-service teachers' development of TPACK for each of the seven domains.

Descriptive statistics were used to compute and screen for linearity, normality, and multicollinearity. Results were reported as mean scores and standard deviations. Paired-sample \(t\)-tests were conducted to assess whether there were statistically significant differences in pre- and post-TPACK scores for all pre-service teachers, as well as those for the four groups examined in the study. Then, a set of two-way MANOVA tests was used to examine whether there were statistically significant differences in the post-TPACK and TPACK-development scores based on prior knowledge and course design (Huberty & Olejnik, 2006). In the MANOVA analyses, prior knowledge and course design were the independent variables and the seven TPACK domains
were dependent variables. These analyses offered univariate follow-up tests to provide results of the various significant multivariate findings. If any significant main effects of the interaction effect were found, *post hoc* tests using Tukey’s HSD were computed.

**Results**

Results are presented in this section. Since the research questions are intertwined in nature, this section is organized around the TPACK domains. First, an overview will be provided to present an overall summary of the findings. Findings on pre-service teachers’ post-TPACK and TPACK-development are also reported.

**Overview of the Results**

Pre-service teachers participated in this study were categorized into four groups based on their prior knowledge (pre-TPACK scores) and which course design they enrolled in. Group 1 pre-service teachers had lower pre-TPACK scores than group 2 pre-service teachers. Both groups were enrolled in the general course design. Group 3 pre-service teachers had lower pre-TPACK scores than group 4 pre-service teachers. These two groups were enrolled in the content-specific course design. Pre-service teachers in group 1 and 3 formed cluster 1 (low pre-TPACK scores), while those in group 2 and 4 consisted cluster 2 (high pre-TPACK scores).

In general, the pre-service teachers participating in this study developed knowledge in all seven TPACK domains after taking the required educational technology course. All domain differences were found to be statistically significant. CK, PK, TK, TCK, and TPACK all had medium effect sizes, while PCK and TPK had small effect sizes. Table 2 provides a synopsis of pre-TPACK, post-TPACK, and TPACK-development scores and the results from the paired-sample *t*-tests from all four groups of pre-service teachers.
Table 2

Pre-service Teachers' Mean TPACK Scores in Four Groups (n = 1,246)

<table>
<thead>
<tr>
<th>TPACK knowledge domains</th>
<th>Group 1 (n = 424)</th>
<th>Group 2 (n = 459)</th>
<th>Group 3 (n = 176)</th>
<th>Group 4 (n = 187)</th>
<th>Total</th>
<th>Difference between pre- and post-surveys</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (SD)</td>
<td>n (SD)</td>
<td>n (SD)</td>
<td>n (SD)</td>
<td>n (SD)</td>
<td>t</td>
<td>df</td>
</tr>
<tr>
<td>CK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>42.03 (5.10)</td>
<td>45.59 (4.60)</td>
<td>42.74 (5.44)</td>
<td>46.20 (4.47)</td>
<td>44.07 (5.19)</td>
<td>3.39*** (5.18)</td>
<td>19.65</td>
</tr>
<tr>
<td>Post</td>
<td>45.42 (5.36)</td>
<td>47.50 (5.32)</td>
<td>49.21 (4.89)</td>
<td>47.00 (5.35)</td>
<td>47.00  (5.32)</td>
<td>1.91*** (4.98)</td>
<td>21.12</td>
</tr>
<tr>
<td>Development</td>
<td>42.74 (5.44)</td>
<td>49.21 (4.89)</td>
<td>47.00 (5.35)</td>
<td>47.00 (5.35)</td>
<td>47.00  (5.32)</td>
<td>3.64*** (3.72)</td>
<td>24.94</td>
</tr>
<tr>
<td>PK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>23.75 (2.96)</td>
<td>28.15 (2.88)</td>
<td>23.76 (3.70)</td>
<td>28.34 (2.92)</td>
<td>26.06 (3.77)</td>
<td>3.32*** (3.70)</td>
<td>21.12</td>
</tr>
<tr>
<td>Post</td>
<td>27.06 (3.42)</td>
<td>29.25 (3.22)</td>
<td>27.40 (3.15)</td>
<td>29.96 (3.13)</td>
<td>28.35 (3.47)</td>
<td>1.10*** (3.72)</td>
<td>24.94</td>
</tr>
<tr>
<td>Development</td>
<td>27.40 (3.15)</td>
<td>29.96 (3.13)</td>
<td>28.35 (3.47)</td>
<td>28.35 (3.47)</td>
<td>28.35 (3.47)</td>
<td>3.41*** (3.72)</td>
<td>35.89</td>
</tr>
<tr>
<td>TK</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>19.81 (3.73)</td>
<td>21.95 (3.88)</td>
<td>19.66 (3.78)</td>
<td>22.89 (3.24)</td>
<td>21.04 (3.93)</td>
<td>2.94*** (3.72)</td>
<td>24.94</td>
</tr>
<tr>
<td>Post</td>
<td>22.75 (3.32)</td>
<td>23.70 (3.62)</td>
<td>23.07 (2.72)</td>
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<td>23.48 (3.39)</td>
<td>1.75*** (3.72)</td>
<td>21.12</td>
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<tr>
<td>Development</td>
<td>23.07 (2.72)</td>
<td>24.99 (2.94)</td>
<td>23.48 (3.39)</td>
<td>23.48 (3.39)</td>
<td>23.48 (3.39)</td>
<td>2.10*** (3.72)</td>
<td>18.30</td>
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<tr>
<td>PCK</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>12.74 (1.94)</td>
<td>15.72 (1.53)</td>
<td>12.29 (2.02)</td>
<td>15.70 (1.52)</td>
<td>14.22 (2.35)</td>
<td>1.99*** (2.24)</td>
<td>18.30</td>
</tr>
<tr>
<td>Post</td>
<td>14.72 (2.29)</td>
<td>16.11 (2.03)</td>
<td>15.14 (1.97)</td>
<td>16.56 (1.96)</td>
<td>15.57 (2.22)</td>
<td>.39*** (2.24)</td>
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<tr>
<td>Development</td>
<td>15.14 (1.97)</td>
<td>16.56 (1.96)</td>
<td>15.57 (2.22)</td>
<td>15.57 (2.22)</td>
<td>15.57 (2.22)</td>
<td>2.85*** (2.52)</td>
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<tr>
<td>TCK</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pre</td>
<td>11.36 (2.59)</td>
<td>14.47 (2.24)</td>
<td>11.30 (2.73)</td>
<td>14.90 (2.26)</td>
<td>13.03 (2.93)</td>
<td>4.29*** (3.18)</td>
<td>35.89</td>
</tr>
<tr>
<td>Post</td>
<td>15.65 (2.09)</td>
<td>16.56 (2.14)</td>
<td>16.18 (1.71)</td>
<td>17.23 (1.84)</td>
<td>16.29 (2.09)</td>
<td>2.08*** (3.21)</td>
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</tr>
<tr>
<td>Development</td>
<td>16.18 (1.71)</td>
<td>17.23 (1.84)</td>
<td>16.29 (2.09)</td>
<td>16.29 (2.09)</td>
<td>16.29 (2.09)</td>
<td>4.88*** (3.21)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>18.07 (2.31)</td>
<td>20.73 (1.79)</td>
<td>17.39 (2.63)</td>
<td>20.62 (1.85)</td>
<td>19.33 (2.55)</td>
<td>3.00*** (2.89)</td>
<td>27.27</td>
</tr>
<tr>
<td>Post</td>
<td>21.07 (2.32)</td>
<td>21.97 (2.20)</td>
<td>20.85 (2.03)</td>
<td>22.13 (2.21)</td>
<td>21.53 (2.28)</td>
<td>1.25*** (2.40)</td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td>21.97 (2.20)</td>
<td>22.13 (2.21)</td>
<td>21.53 (2.28)</td>
<td>21.53 (2.28)</td>
<td>21.53 (2.28)</td>
<td>3.46*** (3.00)</td>
<td></td>
</tr>
<tr>
<td>TPACK</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>25.24 (3.74)</td>
<td>31.59 (3.07)</td>
<td>24.46 (4.27)</td>
<td>31.49 (2.90)</td>
<td>28.41 (4.78)</td>
<td>6.66*** (4.91)</td>
<td>32.97</td>
</tr>
<tr>
<td>Post</td>
<td>31.90 (3.69)</td>
<td>33.81 (3.37)</td>
<td>32.33 (3.20)</td>
<td>34.51 (3.31)</td>
<td>33.06 (3.60)</td>
<td>.22*** (4.86)</td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td>33.81 (3.37)</td>
<td>34.51 (3.31)</td>
<td>33.06 (3.60)</td>
<td>33.06 (3.60)</td>
<td>33.06 (3.60)</td>
<td>7.87*** (4.87)</td>
<td></td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.
Figure 2 illustrates the pre-TPACK and post-TPACK domain scores for each group. The scales in Figure 2 are different because the numbers of questions measuring each TPACK domain were different. These graphs illustrate that both Group 4 and Group 2 pre-service teachers reported higher post-TPACK scores in all seven knowledge domains at the end of the course. Group 1 and Group 3 pre-service teachers also reported relatively higher post-TPACK scores in the seven domains. This preliminary analysis illustrates that prior knowledge and course design could potentially impact pre-service teachers' development of TPACK. Further examination of this result is required.

![Figure 2. Four groups of pre-service teachers' pre- and post-TPACK scores.](image)

**Results of the TPACK Domains**

Several analyses were run to explore the correlations between the TPACK subscales. Pearson correlation coefficients were used to test multicollinearity. The subscales correlated with
each other and there was no evidence of multicollinearity, as assessed by Pearson correlations (|r| < .9). This justifies using a two-way MANOVA for this analysis is appropriate (see Table 3).

Table 3

Pearson Correlations among the Subscales

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. PK</td>
<td>.38**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. TK</td>
<td>.42**</td>
<td>.34**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. PCK</td>
<td>.48**</td>
<td>.67**</td>
<td>.33**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. TCK</td>
<td>.44**</td>
<td>.51**</td>
<td>.44**</td>
<td>.54**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. TPK</td>
<td>.35**</td>
<td>.49**</td>
<td>.38**</td>
<td>.38**</td>
<td>.51**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. TPACK</td>
<td>.39**</td>
<td>.54**</td>
<td>.39**</td>
<td>.52**</td>
<td>.57**</td>
<td>.73**</td>
<td></td>
</tr>
<tr>
<td>TPACK Development</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>

Note. ** Correlation is significant at the .01 level (two-tailed). Strong correlations were bold.

Post-TPACK. A two-way MANOVA test was conducted to examine whether there were differences in pre-service teachers' post-TPACK scores based on prior knowledge and course design. No statistically significant interaction effect between prior knowledge and course design on the combined dependent variables was found, $F(1, 1242) = 1.14$, $p = .33$, Wilks' lambda $\Lambda = .01$, partial $\eta^2 = .01$. However, there was a statistically significant prior knowledge effect on the combined dependent variables, $F(1, 1242) = 24.61$, $p < .0005$, Wilks' $\Lambda = .12$, partial $\eta^2 = .12$. In addition, there was a statistically significant main effect of prior knowledge on all the seven post-TPACK scores (see Table 4). In general, pre-service teachers in cluster 2 (high pre-TPACK scores) reported higher post-TPACK scores compared to those rated by pre-service teachers in cluster 1 (low pre-TPACK scores).
Table 4.

**Post Hoc Test Results of Prior Knowledge Main Effects for Post-TPACK Domains**

<table>
<thead>
<tr>
<th>Post-TPACK Domains</th>
<th>Course Design 1</th>
<th>Course Design 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Difference</td>
<td>95% CI</td>
</tr>
<tr>
<td>Post-CK</td>
<td>2.08</td>
<td>[.139, 2.77]</td>
</tr>
<tr>
<td>Post-PK</td>
<td>2.19</td>
<td>[.175, 2.62]</td>
</tr>
<tr>
<td>Post-TK</td>
<td>.95</td>
<td>[.52, 1.39]</td>
</tr>
<tr>
<td>Post-PCK</td>
<td>1.39</td>
<td>[.111, 1.67]</td>
</tr>
<tr>
<td>Post-TCK</td>
<td>.91</td>
<td>[.64, 1.17]</td>
</tr>
<tr>
<td>Post-TPK</td>
<td>.91</td>
<td>[.61, 1.20]</td>
</tr>
<tr>
<td>Post-TPACK</td>
<td>1.92</td>
<td>[.146, 2.37]</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.

There was a statistically significant course design effect on the combined dependent variables, $F(1, 1242) = 8.18$, $p < .0005$, Wilks’ $\Lambda = .04$, partial $\eta^2 = .04$. In particular, there were statistically significant main effects of course design on six post-TPACK scores, all except for TPK (see Table 5). Overall, it appears that the content-specific course design was more effective in developing pre-service teachers’ TPACK.

Table 5.

**Post Hoc Test Results of Course Design Main Effects for Post-TPACK Domains**

<table>
<thead>
<tr>
<th>Post-TPACK Domains</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Difference</td>
<td>95% CI</td>
</tr>
<tr>
<td>Post-CK</td>
<td>1.73</td>
<td>[.81, 2.64]</td>
</tr>
<tr>
<td>Post-PK</td>
<td>.34</td>
<td>[-.24, .91]</td>
</tr>
<tr>
<td>Post-TK</td>
<td>.33</td>
<td>[-.26, .91]</td>
</tr>
<tr>
<td>Post-PCK</td>
<td>.41</td>
<td>[.04, .78]</td>
</tr>
<tr>
<td>Post-TCK</td>
<td>.53</td>
<td>[.17, .88]</td>
</tr>
<tr>
<td>Post-TPK</td>
<td>-.22</td>
<td>[-.61, .17]</td>
</tr>
<tr>
<td>Post-TPACK</td>
<td>.43</td>
<td>[-.18, 1.04]</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.
TPACK-Development. Another two-way MANOVA test was conducted to examine whether there were differences in pre-service teachers' TPACK-development scores based on prior knowledge and course design. There was not a statistically significant interaction effect between prior knowledge and course design on the combined dependent variables, $F(1, 1242) = .65, p = .72$, Wilks' lambda $\Lambda = .004$, partial $\eta^2 = .004$. However, there was a statistically significant prior knowledge effect on the combined dependent variables, $F(1, 1242) = 55.26, p < .0005$, Wilks' $\Lambda = .24$, partial $\eta^2 = .24$.

There was a statistically significant main effect of prior knowledge for all seven TPACK-development scores (see Table 6). In general, pre-service teachers in cluster 1 (low pre-TPACK scores) reported higher TPACK-development scores than pre-service teachers in cluster 2 (high pre-TPACK scores) in both course designs.

Table 6.

Post Hoc Test Results of Prior Knowledge Main Effects for TPACK-Development Domains

<table>
<thead>
<tr>
<th>TPACK-Development Domains</th>
<th>Course Design 1</th>
<th></th>
<th></th>
<th>Course Design 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Difference</td>
<td>95% CI</td>
<td>$p$</td>
<td>Mean Difference</td>
<td>95% CI</td>
<td>$p$</td>
</tr>
<tr>
<td>CK-Development</td>
<td>1.48</td>
<td>[.79, 2.17]</td>
<td>&lt; .0005***</td>
<td>1.39</td>
<td>[.32, 2.46]</td>
<td>.01**</td>
</tr>
<tr>
<td>PK-Development</td>
<td>2.20</td>
<td>[1.74, 2.71]</td>
<td>&lt; .0005***</td>
<td>2.02</td>
<td>[1.26, 2.77]</td>
<td>&lt; .0005***</td>
</tr>
<tr>
<td>TK-Development</td>
<td>1.19</td>
<td>[.74, 1.64]</td>
<td>&lt; .0005***</td>
<td>1.31</td>
<td>[.61, 2.01]</td>
<td>&lt; .0005***</td>
</tr>
<tr>
<td>PCK-Development</td>
<td>1.60</td>
<td>[1.28, 1.92]</td>
<td>&lt; .0005***</td>
<td>1.99</td>
<td>[1.48, 2.49]</td>
<td>&lt; .0005***</td>
</tr>
<tr>
<td>TCK-Development</td>
<td>2.21</td>
<td>[1.81, 2.60]</td>
<td>&lt; .0005***</td>
<td>2.55</td>
<td>[1.93, 3.17]</td>
<td>&lt; .0005***</td>
</tr>
<tr>
<td>TPK-Development</td>
<td>1.75</td>
<td>[1.40, 2.11]</td>
<td>&lt; .0005***</td>
<td>1.95</td>
<td>[1.40, 2.51]</td>
<td>&lt; .0005***</td>
</tr>
<tr>
<td>TPACK-Development</td>
<td>4.43</td>
<td>[3.85, 5.02]</td>
<td>&lt; .0005***</td>
<td>4.84</td>
<td>[3.93, 5.75]</td>
<td>&lt; .0005***</td>
</tr>
</tbody>
</table>

Note. * $p < .05$; ** $p < .01$; *** $p < .001$.

There was a statistically significant course design effect on the combined dependent variables, $F(1, 1242) = 4.24, p < .0005$, Wilks' $\Lambda = .02$, partial $\eta^2 = .02$. There was a statistically significant main effect of course design for four TPACK-development scores (see Table 7). PK,
TK, and TPK were not significant. Once again, it appears that the content-specific course design was more effective in developing pre-service teachers’ TPACK.

Table 7.

Post Hoc Test Results of Course Design Main Effects for TPACK-Development Domains

<table>
<thead>
<tr>
<th>TPACK Development Domains</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Difference</td>
<td>95% CI</td>
</tr>
<tr>
<td>CK-Development</td>
<td>1.10</td>
<td>[.21, 1.98]</td>
</tr>
<tr>
<td>PK-Development</td>
<td>.52</td>
<td>[-.10, 1.15]</td>
</tr>
<tr>
<td>TK-Development</td>
<td>.35</td>
<td>[.23, .93]</td>
</tr>
<tr>
<td>PCK-Development</td>
<td>.47</td>
<td>[.06, .89]</td>
</tr>
<tr>
<td>TCK-Development</td>
<td>.25</td>
<td>[-.26, .76]</td>
</tr>
<tr>
<td>TPK-Development</td>
<td>.26</td>
<td>[-.20, .72]</td>
</tr>
<tr>
<td>TPACK-Development</td>
<td>.80</td>
<td>[.05, 1.55]</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001.

Discussion

Three main conclusions are drawn from this study. First, the required educational technology course was effective over the nine-year period as it helped pre-service teachers develop knowledge in all seven TPACK domains. Second, prior knowledge affected pre-service teachers' post-TPACK and TPACK-development scores. Pre-service teachers who had higher pre-TPACK scores reported higher post-TPACK scores in all seven knowledge domains. Third, pre-service teachers enrolled in the content-specific course design reported higher post-TPACK scores as compared to the scores reported by pre-service teachers in the general course design. Similarly, pre-service teachers enrolled in the content-specific course design scored higher TPACK-development scores. These results demonstrate that in general, content-specific TPACK course design appears to be more effective for developing pre-service teachers' TPACK.

However, unexpectedly, although pre-service teachers with lower pre-TPACK scores reported higher TPACK-development scores, they still are not as high as pre-service teachers who started
the course with higher pre-TPACK scores. The results indicate that the required educational
technology course still is effective for developing pre-service teachers' TPACK. In addition,
prior knowledge and course design are important variables that deserve attention if teacher
educators hope to maximize the impacts of such a course. The impact of prior knowledge on pre-
service teachers' TPACK will be discussed first, followed by a discussion of the course design
implications.

**Impact of Prior Knowledge on Pre-service Teachers' Development of TPACK**

Results from this study indicate that prior knowledge directly impacts pre-service
teachers’ post-TPACK and TPACK-development scores. This confirms findings from the
learning sciences that prior knowledge and experiences greatly affect how learners perceive and
organize new information and make connections between ideas (Dochy & Alexander, 1995;
Dochy, Segers, & Buehl, 1999; National Research Council, 2000). Within teacher education,
Pierson (2001) found similar results in that pre-service teachers have different levels of
pedagogical expertise and technology proficiency. Because of these differences, pre-service
teachers perceive and approach technology integration differently.

However, pre-service teachers' TPACK development does not indicate they will develop
TPACK strategic thinking (Niess, 2011) and TPACK-practical (Yeh, Hsu, Wu, Hwang, & Lin,
2014). More factors should be considered and included. For instance, three factors were found to
have directly affected pre-service teachers' intentions to integrate technology, their beliefs,
attitudes, and self-efficacy toward technology integration. For example, Teo (2009) identified
that pre-service teachers' technology acceptance and intention to use technology were impacted
by their perceived usefulness, attitudes towards computer use, and computer self-efficacy. When
pre-service teachers recognize the usefulness of technology, they will have positive attitudes
toward technology use, will have more confidence in integrating technology, and are more likely
to integrate technology into practice. Abbitt and Klett (2007) found that perceived comfort with
computer technology was a significant predictor of self-efficacy beliefs toward technology
integration. Sadaf, Newby, and Ertmer (2012) revealed five variables that impact pre-service
teachers' intentions to integrate Web 2.0 tools: 1) beliefs about the value of these technologies
for improving student learning and engagement, 2) its ease of use (behavioral beliefs), 3) its
ability to meet the needs/expectations of digital age students (normative beliefs), 4) the
participants' high self-efficacy in use, and 5) its potential for affording students
anytime/anywhere access to learning and interaction (control beliefs).

Results from this study can initiate additional studies that examine the impact of further
prior knowledge, beliefs, and attitudes on pre-service teachers' development of TPACK, TPACK
strategic thinking, and TPACK-practical (Mishra & Koehler, 2006; Niess, 2011; Yeh et al.,
2014). Since the goal of most teacher education programs is to prepare pre-service teachers who
can meaningfully integrate technology into their classrooms, these findings have practical
implications for teacher educators. In particular, teacher educators should make an effort to
address pre-service teachers' prior knowledge, beliefs, and attitudes during the educational
technology course if offered. Moreover, teacher educators should take steps to design the course
in such a way that aligns with the research-based strategies associated with the TPACK
framework.

Results from this study revealed that the second course design, focusing on content-
specific technology preparation guided by the TPACK framework, was more effective than a
general course design that placed more emphasis on technology and less emphasis on content
and pedagogy specific to content-specific areas. It is interesting to note that although pre-service
teachers in both clusters (low pre-TPACK, high TPACK scores) reported higher TPACK-development scores in the content-specific course design, cluster 1 pre-service teachers reported higher TPACK-development scores than cluster 2 pre-service teachers. This result contradicts the findings from Koh and Chai (2014) that more confident pre-service teachers developed more knowledge compared to less confident pre-service teachers. However, cluster 1 pre-service teachers (low pre-TPACK score) still reported lower post-TPACK scores than cluster 2 pre-service teachers who had higher pre-TPACK scores. Thus, the content-specific course design did not fully close the knowledge gap between these two groups of pre-service teachers as a result of their prior knowledge and experiences.

Unlike the findings of Koh and Chai (2014) that pre-service teachers only developed TPK, TCK, and TPACK, pre-service teachers with higher pre-TPACK scores developed more CK, PCK, TCK, and TPACK while taking the content-specific course design. Pre-service teachers with higher pre-TPACK scores also reported higher post-CK, post-PK, post-TK, post-PCK, post-TCK, and post-TPACK scores. In contrast, pre-service teachers with lower pre-TPACK scores only developed more CK, PCK, and TPACK in the content-specific design, while reporting higher post-CK, post-PCK, and post-TCK scores. These results indicate that growth in the TPACK domains does not automatically result in the increase in all the subscales (Graham, 2011). These results are supported by the correlations that were reported as well (see Table 3). The subscales (i.e., TPACK domains) have different degrees of correlation with each other. These results are similar to those found by Angeli and Valanides (2005, 2009), who depicted TPACK as a distinct body of knowledge and not developed automatically by the increases seen in other sub-domains (Cox & Graham, 2009).
The content-specific course design appeared to be more effective in developing cluster 2 (high pre-TPACK scores) pre-service teachers' TPACK but had less impact on cluster 1 (low pre-TPACK scores) pre-service teachers' development of TPACK. That may indicate that the lack of prior knowledge prevents pre-service teachers from engaging in the course content and activities deeply, which in turn, inhibits their development of TPACK in a required educational technology course. If this is, in fact, true, it would be beneficial to offer the educational technology course later in the preparation program (e.g., during methodology courses) when pre-service teachers had developed more knowledge about content and pedagogy. Alternatively, this finding identifies a need for providing more differentiated instruction and scaffolding for pre-service teachers with consideration of their prior knowledge and experiences (Dochy, 1992). Teacher educators should explore various pedagogies and strategies to assess their effectiveness in closing the gap between these groups. More empirical research is needed in this area.

**Implications of Course Design on Pre-service Teachers' Development of TPACK**

These results suggest that course design does impact pre-service teachers' development of TPACK in a required educational technology course. In particular, the content-specific TPACK course design was more effective as compared to a general course design that focused more broadly on topics related to technology along with some technology integration. These results confer with previous research studies that a stand-alone educational technology course that solely covers technology literacy and awareness is not sufficient (Allsopp, Alvarez McHatton, & Cranston-Gingras, 2009; Herner-Patnode & Lee, 2009; Park & Ertmer, 2008). For example, Abbitt and Klett (2007) compared pre-service teachers' self-efficacy beliefs in three different educational technology course designs. They found that a course design which covers broad issues of technology integration is likely to have a more positive impact on pre-service teachers'
self-efficacy beliefs than a course where the goal is to develop pre-service teachers' proficiency skills with specific computer technology. So, course design does matter in practice, and content-specific technology preparation is more effective in developing pre-service teachers' TPACK.

It is important to investigate reasons why the content-specific course design examined in this study appeared to be more effective in developing pre-service teachers' TPACK. As introduced in the methodology section, the content-specific course design briefly introduces content-specific CK and PK and gives particular emphasis to the interplay between CK, PK, and TK. Every instructional module is developed with the purpose of modeling TPACK lessons in practice, and usually utilizes technological tools at the modification and redefinition levels in the SAMR model (Puentedura, 2006). Besides the content-specific course organization, the instructors also adopt an integrated approach to implementing six research-based strategies into the course (Tondeur et al., 2012). These strategies are presented in the inner circle of the SQD Model, which was created based on a literature review and synthesis of compelling qualitative evidence in preparing pre-service teachers for technology integration. These strategies guided the course development: 1) using teacher educators as role models, 2) reflecting on the role of technology in education, 3) learning how to use technology by design, 4) collaborating with peers, 5) scaffolding authentic technology experiences, and 6) providing continuous feedback (Baran, Canbazoglu Bilici, Albayrak Sari, & Tondeur, 2017). Overall, this study provides empirical evidence for content-specific technology preparation and the usefulness of implementing a holistic approach toward technology integration. Therefore, it is beneficial for teacher educators to consider these two strategies considering the unique context of various teacher education programs.
To utilize the power of content-specific technology preparation, teacher educators should provide content-based instructional modeling and application for pre-service teachers (Niess, 2005). Some suggestions follow for how to implement content-specific technology preparation in practice.

First, the TPACK activity types are useful resources to help pre-service teachers while thinking about and reflecting on the interplay between CK, PK, and TK (Harris et al., 2010). Pre-service teachers can combine and remix the activity types to design TPACK lessons, projects, and units. Since teachers can use these activity types regardless of their teaching philosophy, there is room to teach content-specific pedagogies and instructional models during the process of adoption. Using the TPACK activity types as resources, teacher educators can help guide pre-service teachers through the lesson planning process referencing such design cycles as created by Hammond and Manfra (2009), Harris and Hofer (2009), and by Hutchison and Woodward (2014).

Hofer and Harris (2016) designed and produced a customizable, modularized, TPACK online short course that showcases the utilization of the activity types and real-life modeling from classroom teachers. This short course could also be remixed into existing content-specific modules in an educational technology or content methodology course. Angeli and colleagues also designed a series of curriculum- and classroom-based design scenarios related to TPACK (Angeli, Valanides, Mavroudi, Christodoulou, & Georgiou, 2015). Sharing materials such as these as open educational resources (OERs) would contribute to teacher education and the resources to assist teacher educators when preparing such courses.

It is encouraging that the content-specific TPACK course design was more effective than the general course design in this study. However, it is also interesting to reveal that the content-
specific course design could not close the gap between the pre-service teachers’ pre-TPACK scores and where they ended the course. Although the pre-service teachers' TPACK growth in the two clusters (high and low pre-TPACK scores) parallel each other, pre-service teachers with higher pre-TPACK scores ended the course with higher post-TPACK scores. Although cluster 1 pre-service teacher reported lower pre-TPACK scores as compared to cluster 2 pre-service teachers, they still had lower post-TPACK scores. Therefore, pre-service teachers with different prior knowledge and experiences need differentiated instruction and scaffolding during an educational technology course. Two specific emerging pedagogies being used in the higher education, adaptive e-learning systems and team-based learning (TBL) might be promising approaches to use for such a course.

First, designing an adaptive e-learning system might be an effective strategy for providing differentiated instruction to pre-service teachers based on their prior knowledge. Such an approach incorporates learners' prior knowledge, background, cognitive traits, study goals, language, motivation level, and learning styles during the design to provide students' with adaptive learning experiences (Germanakos, Tsianos, Lekkas, Mourlas, & Samaras, 2008; Thalmann, 2014). The adaptive system can offer advice to teachers and students through computerized and statistical algorithms that could not be fulfilled by traditional learning and teaching (Truong, 2016). In practice, this approach is found to be effective in improving students' learning performance (Kurilovas, Kubilinskiene, & Dagiene, 2014; Lin, Yeh, Hung, & Chang, 2013; Yang, Hwang, & Yang, 2013). By considering students' prior knowledge and learning styles during the design of the adaptive e-learning system, both students and teachers can benefit. Students will be able to address the gaps in their knowledge bases and learn about their unique learning styles, enabling them to be more confident in their learning (Herod, 2004). Teachers can
offer ongoing instruction and constructive feedback to individual students or teams when and where they need (Stash, 2007). Furthermore, this approach utilizes the potential of incorporating the student models created through learning analytics and educational data mining into the adaptive e-learning system. Instructors could gain insight into learners' learning strategies and behaviors. Thus, teachers could guide instruction for individual learners through multimodal and affective learning opportunities (Chrysafiadi & Virvou, 2013; Papamitsiou & Economides, 2014).

Second, adopting team-based learning (TBL) pedagogy in lecture and lab could facilitate peer learning and teaching. The TBL pedagogy requires students to prepare for class, thus, makes it a suitable combination with the adaptive e-learning system. TBL also asks instructors to form heterogeneous teams, which means that each team is composed of pre-service teachers with different prior knowledge and different experiences (Michaelsen, Knight, & Fink, 2002). In class, pre-service teachers could work in teams to interpret the topics and examples given for a particular educational context. They could collaborate on observing, discussing, and reflecting on the affordances and limitations of the technology tools, the feasibility of the teaching strategies, and the value of the modeling (Lim & Chan, 2007). During this process, pre-service teachers could learn from each other and help others deepen their understanding of technology integration. While teams, pre-service teachers could reflect on the roles of technology in education, discuss their attitudes toward technology integration, and deliberate about the challenges and experiences of technology integration in classrooms (Kay, 2006). Based on the performance of different teams, the instructors have the opportunity to provide more individualized instruction and scaffolding that addresses particular questions and issues. Researchers are promoting this kind of collaborative group work and have experienced positive
outcomes, such as enhanced learning outcomes and reflective practices (Agyei & Voogt, 2012; Angeli & Valanides, 2009). Research on investigating the outcomes of adopting TBL in such a course will provide more insight into the usefulness of collaboration on developing pre-service teachers’ TPACK.

Teacher educators are role models to pre-service teachers with respect to technology integration (Kaufman, 2015). Modeling from other teachers is a strong motivator for pre-service teachers (e.g., Angeli & Valanides, 2013; Calik, 2013; Figg & Jamani, 2011; Graham et al., 2009; Haciomeroglu, Bu, Schoen, & Hohenwarter, 2011; Jaipal & Figg, 2010; Jang & Chen, 2010; Kennedy-Clark, 2011; Kramarski & Michalsky, 2010; Mouza & Karchmer-Klein, 2013; Schnittka & Bell, 2009; Tokmak, Yelken, & Konokman, 2013). Future research could examine how modeling and how much modeling impacts pre-service teachers' development of TPACK.

Finally, the results from this study support findings from other work with smaller sample sizes, which demonstrates the effectiveness of a stand-alone educational technology course on developing pre-service teachers' TPACK. Additional research is needed to investigate multi-year and longitudinal studies to explore the impact of prior knowledge, course design, and technology preparation on developing pre-service teachers' TPACK.

Limitations

There were a few limitations to consider of this study. Many of the constraints present opportunities for future work. First, although this study used a relatively large data set, the participants were recruited from a teacher education program in a large Midwestern land-grant university. It might be possible that these pre-service teachers are not representative of pre-service teachers across U.S. or internationally. Similarly, the research focused on two specific course designs of a required educational technology course. Although some aspects of this
course are probably common to similar courses at other institutions, certain parts of the course might be unique and do not represent other possible designs of such courses. Although the results of this study were informative, the focus on this particular course limits the potential of generalizability of the results to other courses from different teacher education programs.

Second, a validated TPACK survey was used to collect subjective responses from pre-service teachers on their perceptions of development of TPACK. This approach has risks in that pre-service teachers might respond with social desirability bias (Fisher, 1993). Moreover, the measured gains in pre-service teachers' self-reported TPACK over time might reflect the increase in their confidence of possessing TPACK or toward particular types of technology integration, instead of an actual increase in knowledge (Lawless & Pellegrino, 2007; Schrader & Lawless, 2004). However, for this study, an increase in pre-service teachers' confidence might be enough for a required educational technology course. Moreover, the main purpose of the course is to develop pre-service teachers' TPACK, infuse positive beliefs in pre-service teachers towards technology integration, and align the technology preparation with those in methods courses. However, longitudinal studies are still greatly needed to track pre-service teachers at other time periods during their teacher education programs to see the gradual development of TPACK.

**Conclusion**

The current study is unique in that it included a multi-year sample of pre-service teachers completing a required educational technology course. It is important to conduct longitudinal studies because results can provide more empirical evidence to support findings in previous research of similar courses with small sample sizes and one-time data collection approaches (Chai et al., 2011; Koh & Divaharan, 2011; Schmidt et al., 2009). Results from this study, along indicate that a stand-alone educational technology course can be useful in developing pre-service
teachers’ TPACK. In addition, prior knowledge is a critical variable for pre-service teachers' post-TPACK and TPACK-development. Although course design can positively affect pre-service teachers' post-TPACK and TPACK-development scores, course instructors should keep prior knowledge in mind. In this study, pre-service teachers with less prior knowledge reported gains in TPACK-development but still did not report higher post-TPACK scores than pre-service teachers who started the course with higher pre-TPACK scores. Additionally, longitudinal studies that examine the design of technology preparation in a teacher education programs are still greatly needed. More work that specifically addresses course design and instructional materials created to develop pre-service teachers' TPACK will help inform in order to improve pre-service teachers’ development of TPACK and practices of preparing pre-service teachers for technology integration in classrooms.

References


National Education Association. (2008). Technology not being used effectively in schools: Teachers need professional development and support to implement school technology.


CHAPTER 5. GENERAL CONCLUSION

Summary

Shulman’s PCK framework provides educational researchers with a starting point to conceptualize and measure the knowledge teachers need to teach well (Shulman, 1986, 1987). In the late 1990s, the original PCK framework seemed to fall short in addressing all the knowledge domains teachers needed, especially in technology-infused classrooms. Therefore, researchers began to reconceptualize the PCK framework by including technological knowledge in the framework (Angeli & Valanides, 2005; Keating & Evans, 2001; Koehler & Mishra, 2005a, 2005b; Margerum-Leys & Max, 2002; Niess, 2005; Pierson, 1999). In 2006, Mishra and Koehler delineated seven knowledge domains in their proposed TPCK framework and stressed the importance of each knowledge domain as a crucial component of teacher knowledge. After almost ten years of discussion and research, the TPACK framework has been widely accepted and adopted by educational researchers to help frame their studies and investigations. As a result, research studies on measuring pre-service teachers’ development of TPACK are numerous (e.g., Tondeur et al., 2012; Willermark, 2017). Specifically, five types of research methodologies are commonly used for these investigations (Gall, Gall, & Borg, 2007; Koehler, Shin, & Mishra, 2012). These five methods include: 1) Self-Reported measures (i.e., Likert scale), 2) Open-Ended questionnaires (i.e., written responses from open-ended questions), 3) Performance assessments (i.e., rubric, performance task, artifact, lesson plan, reflection paper, and content analysis), 4) Interviews, and 5) Observations (i.e., field notes, video recordings of a lesson).

Positive outcomes have been reported when examining pre-service teachers’ development of TPACK during their completion of a teacher education program (e.g., Chai,
Koh, & Tsai, 2016; Schmidt et al., 2009; Tondeur et al., 2012). However, many pre-service teachers from teacher education programs still conclude that they feel unprepared for integrating technology into their classrooms when they graduate (Angeli & Valanides, 2009; Ertmer & Ottenbreit-Leftwich, 2010; Kay, 2006; Moursund & Bielefeldt, 1999; Sang et al., 2010; Tondeur et al., 2013). Thus, there is still a significant need to examine how pre-service teachers develop their TPACK during teacher education programs, especially in the required educational technology courses, which is one method commonly used by most teacher education programs (Willermark, 2017). Very few studies have explored how different course designs of the required educational technology course and pre-service teachers’ prior knowledge might impact their development of TPACK. Therefore, this dissertation focused on examining any potential relationship between prior knowledge, course design, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores in a required educational technology course. This dissertation is comprised of three journal articles all focused on using a longitudinal approach to document pre-service teachers’ development of TPACK.

The first article, "Literature Review: Technological Pedagogical Content Knowledge (TPACK) - Research and Practice in Teacher Education," offered an extensive review of literature organized around topics related to the historical development of the TPACK framework and the development of TPACK specific to pre-service teachers. In particular, four topics were explored, 1) the history of the TPACK framework, 2) further conceptualizations of the TPACK framework, 3) TPACK research in teacher education, and 4) TPACK in practice in teacher education programs. This paper served as the foundation for the next two papers and highlighted the need to conduct a longitudinal study focused on pre-service teachers’ development of TPACK. Future research directions for the TPACK studies were also discussed.
First, there is still a need to revise and refine the definitions and distinctions to reflect the characteristics of technology integration in content areas, especially in literacy, a content area less investigated in the past. At the same time, it might be worth investigating whether the TPACK knowledge domains look different for pre-service, novice, and experienced teachers. Second, more studies are needed to investigate the learning outcomes of pre-service teachers at different stages during their teacher education program. Another important next step for TPACK research is to further theorize the “context” component so researchers can have a shared understanding of context and apply it to their work. Finally, it is also essential to provide more empirical evidence by investigating whether TPACK is an integrative or transformative concept, as well as whether it is domain-general or domain-specific. This line of research has direct implications for practices in teacher education programs.

The second article, "Longitudinal Study of Pre-service Teachers’ Development of TPACK," focused specifically on pre-service teachers’ prior knowledge and whether their prior knowledge affected their post-TPACK and TPACK-development scores. Using a two-step cluster analysis, a two-group model based on pre-service teachers' pre-TPACK scores and demographic characteristics was chosen as the best model fit. In general, pre-service teachers in cluster 1 reported lower pre-TPACK scores. In contrast, pre-service teachers in cluster 2 reported higher pre-TPACK scores. Findings also revealed that cluster 2 pre-service teachers still had higher post-course TPACK scores compared to cluster 1 pre-service teachers. However, cluster 1 pre-service teachers had higher TPACK-development scores. Findings from this study highlight the need to continue investigating the interaction effects of course design, prior knowledge, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores.
The third article, "Impact of Prior Knowledge and Course Design on Pre-service Teachers' TPACK Development in a Required Educational Technology Course," built upon the findings from Chapter 3 and explored the interaction effects of course design, prior knowledge, and technology preparation on pre-service teachers' post-TPACK and TPACK-development scores. All three variables were found to be crucial variables that affected pre-service teachers' post-TPACK and TPACK-development scores. However, there were no statistically significant interaction effects between prior knowledge and course design. The content-specific course design utilized content-specific strategies aligned with the TPACK framework and appeared to be more effective in developing pre-service teachers' TPACK.

This study is unique in that it included a multi-year sample (i.e., nine years) of pre-service teachers enrolled in a required educational technology course. Longitudinal investigations are important because such research provides additional empirical evidence to add to the findings from previous research of similar courses with small sample sizes and one-time data collection points (Chai et al., 2011; Koh & Divaharan, 2011; Schmidt et al., 2009). It would be beneficial for other scholars in the field to replicate such a study in other educational technology courses and in different contexts. Longitudinal studies that examine the design of technology preparation throughout teacher education programs are still greatly needed. It is also essential to write about and share the design cases and instructional materials created to develop pre-service teachers' TPACK nationally and internationally to further improve the practices of preparing pre-service teachers for technology use and integration.

Collectively, these three articles provide a review of the relevant TPACK literature and two empirical studies investigating pre-service teachers' development of TPACK. The results reveal that prior knowledge is a major variable and teacher educators should implement
instructional strategies and provide differentiated instruction that focuses on pre-service teachers’ prior knowledge and experiences. Moreover, the required educational technology course was consistently effective over nine academic years, which demonstrates such a course can be a useful method for developing pre-service teachers’ TPACK. Furthermore, when the course was redesigned with a targeted focus on using content-specific (i.e., math, literacy, social studies, science) strategies guided by the TPACK framework, pre-service teachers’ reported higher post-TPACK and TPACK-development scores compared to those enrolled in a more general course design. Overall, findings from this dissertation offer empirical evidence to the field and identify approaches to better develop pre-service teachers’ TPACK.

**Recommendations for Future Research**

The findings of this dissertation shed light on some future directions of TPACK research. First, further investigation is needed to explore how pre-service teachers' prior knowledge and experiences impact their development of TPACK and how those results might inform TPACK strategic thinking and innovative approaches to technology integration in teacher education programs and K-12 classrooms. Second, this dissertation examined the impact of course designs of a required educational technology course. Similar research should be conducted in other teacher education contexts to explore how technology is taught and how technology integration is addressed throughout an entire teacher education program. Comparing and contrasting different course designs in consideration of specific contextual factors might extend these research findings. Third, investigating technology integration throughout other areas in teacher education programs (such as foundation courses, methodology courses, practicums, field experiences, and student teaching) is still needed. The goal for most teacher education programs is to see technology infused throughout the entire preparation program (Ottenbreit-Leftwich,
Glazewski, Newby, & Ertmer, 2010; Wetzel et al., 2014), but most efforts have fallen short, so research is still needed to inform the practices on how to develop pre-service teachers’ TPACK. Finally, implementing different instructional approaches such as team-based learning and design adaptive e-learning systems might help to maximize the impact of the stand-alone educational technology course. Additional work and empirical research in this area will provide more information on the usefulness of such approaches.

References


APPENDIX. IRB APPROVAL FORM

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Date: 5/31/2017
To: Dr. Denise Crawford
   N031 Lagomarcino Hall

From: Office for Responsible Research
Title: Survey of Preservice Teachers’ Development of Technological Pedagogical Content Knowledge (TPACK)
IRB ID: 17-118

Study Review Date: 5/31/2017

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

1. Research conducted in established or commonly accepted education settings involving normal education practices, such as:
   - Research on regular and special education instructional strategies or
   - Research on the effectiveness of, or the comparison among, instructional techniques, curricula, or classroom management methods.

2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
   - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
   - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- You do not need to submit an application for annual continuing review.

- You must carry out the research as described in the IRB application. Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. Only the IRB or designee may make the determination of exemption, even if you conduct a study in the future that is exactly like this study.

Please be aware that approval from other entities may also be needed. For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. An IRB determination of exemption is no way implies or guarantees that permission from these other entities will be granted.

Please don’t hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.