EXPLORING AND EXEMPLIFYING PRE-SERVICE TEACHERS' COMPUTATIONAL THINKING IN THE CONTEXT OF TECHNOLOGY INTEGRATION

by

Hui Yang

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ABSTRACT

Computational Thinking (CT) has been recognized as a fundamental analytical thinking skill required for all students to navigate the digital world (CCSS, 2010a, 2010b; NGSS, 2010; Wing, 2006). Therefore, it is necessary to promote CT in K-12 settings in order to equip students with a CT-related skillset (ISTE, 2016). Implementation of CT in classrooms, however, relies on teachers' knowledge and dispositions in relation to designing CT-infused lesson (Barr & Stephenson, 2011; Mouza, Yang, Pan, Ozden & Pollock, 2017b).

This work addresses a strategic starting point to prepare future teachers with the knowledge and skills needed to infuse CT in K-8 curricula. One hundred and thirty-five pre-service teachers participated in an educational technology course offered through a four-year teacher education program in the United States. This course was redesigned to weave CT and educational technology into the instructional design. For the purpose of this work, I conducted a two-phase mixed-methods investigation to gather progressive and precise understandings of pre-service teachers' CT implementation throughout their participation in the course. The Phase I study focused on exploring how pre-service teachers (N=135) developed CT related knowledge and practices with technology integration. The Phase II study explored and exemplified pre-service teachers' CT trajectories throughout their participation in the redesigned educational technology course using a subset of participants (N=57).

Findings of this work contribute to understanding teacher knowledge in relation to CT implementation in K-8 settings. They also help underline factors that influence teachers' decisions related to infusing CT in classrooms.

Chapter 1

INTRODUCTION

Background of the Problem

Computational Thinking (CT) is an essential skill needed for all in the U.S. economy. Data provided by the U.S. Bureau of Labor Statistics (BLS) asserted that Science, Technology, Engineering, and Mathematics (STEM) would be the future of the economy (Vilorio, 2014). In particular, computer science (CS) related occupations are predicted to be in high demand from 2012-2022 (Vilorio, 2014). According to the BLS report, STEM occupations often require professionals to use their knowledge of "science, technology, engineering, or math to try to understand how the world works and to solve problems" (p. 5); moreover, STEM professionals are often required to use computers and other tools throughout their work. Although the U.S. economy anticipates approximately 9 million STEM-related occupations between 2012-2020, females and minorities have been found to be dissuaded from a career in CS or STEM (Avendano, Renteria, Kwon, & Hamdan, 2019; DuBow, Farmer, Wu, & Fredrickson, 2013; Feder, 2012; National Center for Women & Information Technology [NCWIT], 2017; Richards, & Terkanian, 2013; Vilorio, 2014). In 2014, only 14.1% of CS major graduates were female, a figure that increased only slightly to 17.9% in 2017. Minorities' graduation rates in CS were under 20% in 2014 and gradually increased to be about 25% in 2017. This slow progress

revealed that diversity in computing is still lacking (NCWIT, 2017; National Center for Science and Engineering Statistics, 2019).

To better prepare future generations to be qualified for STEM jobs, NSF and the U.S. Department of Education launched a new initiative called "CS for All". This national effort aims to provide accessible CS education to all students nationwide, and particularly to broaden CS participation among females and minorities. The essence of the "CS for All" program is to empower all students with CT (Smith, 2016). CT has been recognized as an important mechanism to promote CS into K-12 settings (Yadav, Krist, Good, and Caeli, 2018); moreover, it is an analytical skill that is widely required in every aspect of an individual's life from personal to professional (Computer Science Teachers' Association [CSTA] & International Society for Technology in Education [ISTE], 2011; Selby, 2015; Wing, 2006). Early and extensive exposure to CT is promising for engaging students in developing a range of concepts of computing (Bers, Flannery, Kazakoff, & Sullivan, 2014) and for motivating students (especially females) in approaching STEM fields (Shute, Sun, & Asbell-Clarke, 2017). Therefore, CT should be provided to students starting at an early age to increase the participation of women and minority groups in computing and STEM-related fields (Main & Schimpf, 2017).

Definition and Role of CT in Education

Generally speaking, CT is "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Cuny, Snyder & Wing, 2010, as cited in Wing, 2011, p. 1). More specifically, CT represents problem solving and

metacognitive abilities. According to Anderson (2016), there are five core steps that are involved in CT: a) decomposition (e.g., breaking a problem down into a series of manageable steps); b) pattern recognition (e.g., looking for repetitive patterns in the problem to design an efficient solution); c) abstraction (e.g., representing the solution in a generalized form); d) algorithm design (e.g., designing the solution in a systematic way) and e) evaluation (e.g., ensuring all algorithmic steps are followed through to a comprehensive solution). To summarize, problem-solving, that means formulating a problem and designing a solution based on the principles of computing is often used to define CT (Google, 2015; Lu & Fletcher, 2009).

In 2006, Wing proposed that CT is a fundamental analytical skill for 21st-century citizens, which led to CT being introduced into K-12 education. Later, in 2010, the National Research Council (NRC) echoed Wings' support for infusing CT to everyone by defining CT as "comparable to other basic cognitive abilities that the average person in modern society is expected to possess" (p. 13). Similarly, the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) highlighted the importance of CT in K-12 classrooms as a problem-solving methodology which encompasses formulating problems and seeking optimized solutions that can be automated, transferred and effectively executed by human or computers (CSTA & ISTE, 2010; Barr & Stephenson, 2011; Wing, 2006).

CT as a problem-solving skill, which often involves a series of CS concepts and characteristics, has been considered as an essential ability for STEM professionals to succeed professionally (Angeli, Voogt, Fluck, Webb, Cox, Malyn-Smith, & Zagami,

2016; Barr & Stephenson, 2011; Yadav, Hong & Stephenson, 2016; Yadav, Mayfield, Zhou, Hambrusch & Korb, 2014; Vilorio, 2014). Moreover, it has been recognized as a critical skill for the next generation to thrive in the digital era (ISTE, 2016). Therefore, infusing CT into K-12 education has implications for preparing younger generations with the fundamental skillset needed to succeed in their future education and career (Yadav, Krist, Good, & Caeli, 2018).

Statement of the Problem

In 2016, the International Society for Technology in Education (ISTE) *Standards for Students* emphasized the need for younger generations to develop CT skills needed to navigate a digital world. However, preparing teachers for computing education and ensuring gender equity remain huge challenges (Grover & Pea, 2013). Hence, it is essential to help school teachers develop CT knowledge and pedagogies needed to facilitate school students' CT development (Bower & Falkner, 2015; Mouza, Yang, Pan, Ozden, & Pollock, 2017b; Yadav, Gretter, Good, & McLean, 2017).

To date, research studies investigating how K-8 teachers develop and implement CT knowledge and skillset can be grouped into three categories: 1) studies that focus on developing teachers' CS knowledge and skills, such as programming, in order to help develop teachers' CT knowledge (Angeli et al., 2016; Cetin, 2016; Yadav, Zhou, Mayfield, Hambrusch, & Korb, 2011); 2) studies that measure teachers' CT knowledge and misconceptions to inform future research steps in teacher education (Bower & Falkner, 2015; Sadik, Leftwich, & Nadiruzzaman, 2017; Yadav et al., 2017); and 3) studies that investigate teachers' knowledge, attitudes or self-efficacy as they develop and

implement CT within a particular content area (Jaipal-Jamani & Angeli, 2017). For instance, Jaipal-Jamani and Angeli (2017) demonstrated how pre-service teachers developed self-efficacy, science knowledge, and CT knowledge together by participating in a 12-week robotics intervention embedded in a science method course. Reviewed studies that addressed CT integration with *all* core content areas in K-8 settings were scarce; instead, studies mostly situated CT closely with CS (Angeli et al., 2016; Yadav et al., 2016) or STEM fields, such as science (Lehtinen, Nieminen & Viiri, 2016) and mathematics (Hughes, Gadanidis, & Yiu, 2016).

Helping teachers learn how to infuse CT with another discipline is essential for allowing students to recognize and investigate linkages among CT knowledge, disciplinary knowledge, and real-life applications (Barr & Stephenson, 2011; CSTA & ISTE, 2011; Weinberg, 2013). Despite some emerging research, more studies are needed related to teacher preparation for CT integration that address four identified needs. First, although some studies to date have explored how CT was perceived by teachers from different content areas, more work is needed to explore teachers' knowledge as they integrate CT into K-8 education across all subject areas instead of individual disciplines. Second, it is crucial to examine key strategies and effective learning models that help prospective teachers integrate different types of knowledge with CT. Third, existing research reflected a need for future studies that identify and illustrate pre-service teachers' learning trajectories in relation to CT integration (Yadav et al., 2017). Finally, most studies to date utilized either quantitative or qualitative methodologies alone. More

studies are needed utilizing mixed methods approaches, which have the potential to examine the complex relationship between CT and teacher knowledge (e.g., Cetin, 2016).

Purpose of the Study and Its Conceptual Framework

Based on the identified research gaps, the current study targets two important issues. From a conceptual standpoint, it explores how pre-service teachers conceptualize and implement CT in K-8 classrooms. From a methodological standpoint, it employs a rigorous mixed method study design to examine pre-service teachers' perceptions of CT concepts and their integration in K-8 classrooms. As noted, most studies to date utilized a singular method (e.g., quantitative or qualitative methods), which had limitations in triangulating evidence. A mixed methods approach provides potential advances for researchers to study teacher knowledge in relation to CT using both quantitative and qualitative approaches that help strengthen the credibility and validity of the findings (Johnson & Onwuegbuzie, 2004).

Given the prevalence of technology in today's classrooms, one way to infuse CT into K-8 is to equip teachers with the knowledge and skills they need to weave CT ideas and technology into their everyday pedagogical activities (Lye & Koh, 2014). Since its inception, the framework of Technological Pedagogical Content Knowledge (TPACK) has provided a unifying lens for examining teacher knowledge for effective use of technology, methodologies, and practices across the curriculum. TPACK provides a useful framework for studying teacher knowledge in relation to CT because computational tools frequently play a central role in CT-related concepts and practices (Angeli et al., 2016; Mouza et al., 2017b). The construct of TPACK is used in two ways

in this work: As a framework for guiding the design of an educational technology course and as an analytic lens for examining pre-service teachers' learning outcomes illustrated in course products. More specifically, this work addresses the construct of TPACK in relation to CT (see Figure 1.1), which focuses on pre-service teachers' understanding of how CT-related concepts, computing tools, and practices (TK-CT) can be combined with disciplinary content (CK) and pedagogical strategies (PK) to achieve effective technology integration in CT-infused contexts (TPACK-CT).

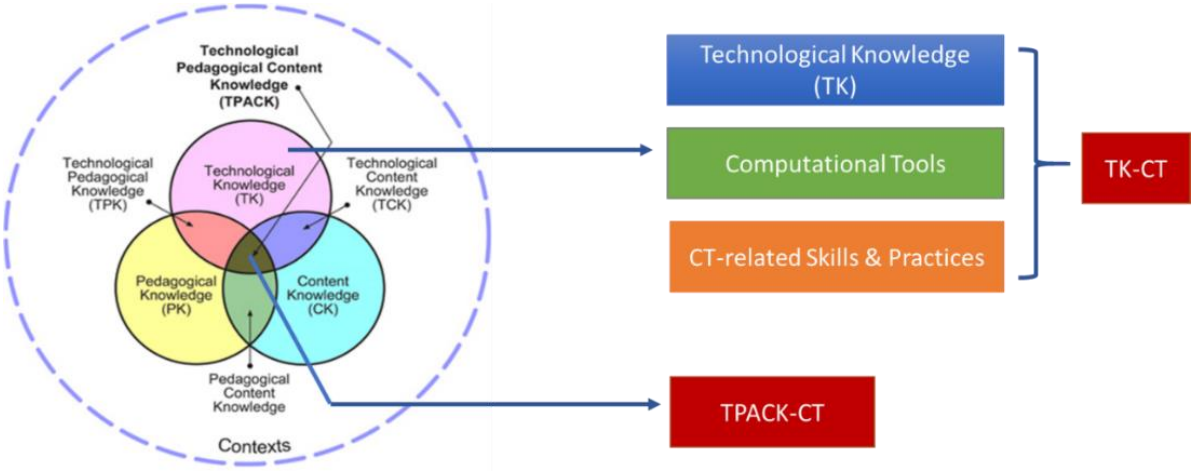


Figure 1.1 TPACK-CT framework (Based on Mishra & Koehler, 2006).

The purpose of this dissertation is to examine how pre-service teachers develop an understanding of CT knowledge, including its application to school curricula and everyday pedagogical activities. This work is situated in the context of a 15-week technology integration course, which has been redesigned to support the development of pre-service teachers' CT knowledge and skills. By focusing on a purposefully selected group of pre-service teachers, this work also intends to exemplify trajectories related to

participants' understanding of CT concepts, selection of CT tools, and consideration of content and pedagogical decisions in K-8 classrooms. Consequently, the dissertation study was executed through two phases, described below, according to the two overarching purposes.

Overview of the Study Methodology and Research Questions

This dissertation was carried out through two phases that helped examine pre-service teachers' trajectories in relation to their understanding of CT concepts, selection of CT tools, and considerations of content and pedagogical decisions. Figure 1.2 outlines the overall research design and demonstrates the relationship between these two phases.

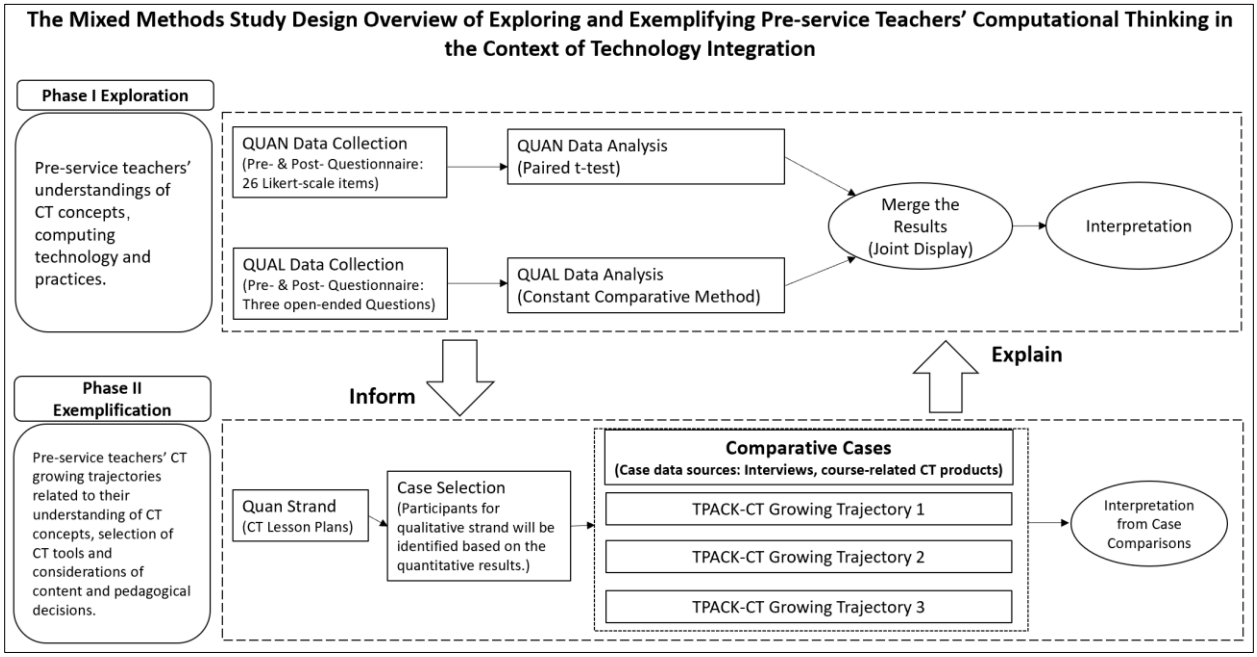


Figure 1.2 The Mixed Methods Study Design Overview (Phase I & Phase II).

Phase I Study. The Phase 1 Pilot study examined how pre-service teachers' participation in the redesigned educational technology course influenced their

understanding of CT related concepts, computing tools, and application in classroom contexts. A convergent parallel mixed method design was utilized in Phase I to allow survey data (quantitative strand) and open-ended responses (quantitative strand) to be collected in parallel, analyzed separately, and then merged (Creswell & Plano-Clark, 2017; Johnson & Onwuegbuzie, 2004). The reason for collecting both quantitative and qualitative data was to corroborate results from two forms of data to bring greater insights into the issue at hand than what could be obtained by either type of data separately (Bustamante, 2017). Accordingly, three research questions were developed to guide the mixed methods study in Phase I:

1. How does participation in a redesigned educational technology course influence pre-service teachers' understanding of CT as illustrated in pre and post survey data? (Quantitative Research Question)
2. How do pre-service teachers perceive the implementation of CT into K-8 core content areas, including the role of technology during CT implementation? (Qualitative Research Question)
3. To what extent do pre-service teachers' perceptions of CT implementation as illustrated in the qualitative results relate to their CT understanding as illustrated in the quantitative survey results? (Mixed-Methods Research Question)

Phase II Study. The second phase examined pre-service teachers' development in CT implementation. An explanatory mixed-methods case study design was conducted to fill the method gap, where detailed voices and participant perspectives are often lacking to support the explanation of quantitative relationships (Creswell & Plano-Clark, 2017).

An explanatory mixed methods case study design was conducted to analyze participants' TPACK-CT lesson plan data followed by examining representative cases' course artifacts and interviews (Watson, Watson, Yu, Alamri, & Mueller, 2017). Ultimately, all data sources were integrated to generate in-depth and valid cases that represented pre-service teachers' CT trajectories (Ivankova, 2014). Three research questions were developed to guide the mixed methods study in Phase II:

4. What trajectory of TPACK-CT do preservice teachers exhibit during their participation in the redesigned educational technology course? (Quantitative Research Question)
5. How is TPACK-CT represented in pre-service teachers' course-related CT products? (Qualitative Research Question)
6. What are the similarities and differences across the different TPACK-CT trajectories? (Mixed-Methods Research Question)

Significance of the Study

This study focuses on identifying pre-service teachers' CT trajectories, an area of study that has not yet been fully investigated in prior research. As such, the study addresses a research gap related to how pre-service teachers conceptualize and implement CT within their teaching practices. Additionally, the study employs complex mixed-methods study designs and aims to provide rigorous and integrated findings among multiple data sources. Hence, the study makes a methodological contribution related to pre-service teachers' CT development.

Organization of the Dissertation

In-depth information about the study is provided in subsequent chapters. More specifically, chapter 2 provides the theoretical framework and empirical literature on CT and teacher learning. This chapter starts with a review of the history and development of CT, then moves on to describe current issues that hinder CT integration in K-8 settings, including teachers who are capable of infusing CT into the classrooms. Subsequently, analysis and synthesis of studies related to teacher education in CT are presented along with a justification for grounding the dissertation in the TPACK framework. Chapter 3 represents the methodology of the study focusing on its design, participants, research context, and measures to the data analytic plan. Chapter 4 delineates the results of the study, corresponding to each research phase and research question. Finally, chapter 5 synthesizes and interprets the results, acknowledges limitations of the study, and discusses the implications for future researchers and policymakers.

Chapter 2

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Chapter Overview

The purpose of this dissertation is to explore and exemplify the development of pre-service teachers' CT in the context of technology integration. This inquiry drew from relevant literature and aimed to fulfill identified research gaps in relation to teacher education in CT. The literature review is organized into four themes that represent the argument for infusing CT into the K-12 curriculum in the manner proposed. Theme 1 presents the justification for CT instruction in K-12 by tracing the historical roots of CT and its development in education. Theme 2 focuses on the current state of CT integration in the field of education. Approaches for implementing CT in educational settings, including a notable teaching and learning method that aims to advance learners' CT development, and factors that hinder CT integration in K-8 settings are presented. Theme 3 synthesizes studies focusing on preparing in-service and pre-service teachers to implement CT in their classrooms, with a particular focus on the latter. Advantages and challenges of teacher training modules and programs are analyzed followed by the identification of research gaps in the pre-service teacher education literature. Theme 4 provides a justification for why the Technological Pedagogical and Content Knowledge (TPACK) framework can be used to address research gaps in the literature.

Table 2.1 below provides a summary of the key ideas that emerged from the research literature for each theme.

Table 2.1 Overview of Key Ideas Related to CT Development and Teacher Education.

Theme	Purposes	Key Ideas
1	Introduce the evolution of CT in education, placing it as an imperative skill for all students in the 21st century.	CT has been recognized as a problem-solving process, which involves both computing and cognitive domains. In 2006, Wing argued that CT is a fundamental analytical skill for everyone. Henceforth, educational policies and organizations have been advocating for the need to equip students with CT competencies, by updating the expectations to further its integration into K-12 settings.
2	Describe approaches that have been used to support the implementation of CT in education.	CT has been embedded into CS curricula with a focus on CS concepts and terminologies. However, emerging research studies indicated that CT should be taught early and often in order to prepare students to adequately develop critical thinking and problem-solving skills. Therefore, new initiatives have been put forth to expose younger learners in computing, most often through programming.
	Provide analysis of current issues related to expanding CT in education.	Merely exposing students to CT through learning programming leads to misconceptions that CT is equivalent to programming. Therefore, more effort is required to bridge the chasm between CT and other disciplines in K-8 including literacy, science, and social studies. Importantly, few teachers are capable of infusing CT in their

		classrooms, which hinders CT implementation in K-8 contexts.
3	Examine teacher training modules that have been implemented and studied to facilitate teachers' CT understandings and implementation.	Current efforts aim at equipping teachers with knowledge and skills to infuse CT into their classrooms. These efforts can be divided into two categories: professional development for in-service teachers and training for pre-service teachers in teacher education programs. Compared with in-service teacher professional development programs, emerging studies showed that various approaches had been utilized to prepare pre-service teachers to embed CT into their future classrooms.
	Review prior work related to the design and purposes of pre-service training modules, as well as methods that have been employed for investigating pre-service teachers' CT development.	Only a few studies specified their learning modules and design rationales for training pre-service teachers. None of the studies presented evidence to illustrate pre-service teachers' sequential development in relation to CT implementation. More rigorous studies are needed for investigating pre-service teachers' CT development and implementation.
	The TPACK framework can serve as a starting point for formulating and evaluating the design of CT training modules/programs for pre-service teachers.	Using technology as a starting point to introduce pre-service teachers to CT concepts and practices was found to be a common practice in studies promoting pre-service teachers' CT understanding and implementation. Given the prevalence of technology in today's classrooms, one way of infusing CT into K-8 is to equip teachers with the knowledge and skills to weave CT ideas and tools into their everyday pedagogical activities. Therefore, TPACK could be utilized to instill

		CT into teaching practice through increasing teachers' technological knowledge in computational tools.
4	Present a holistic description of the components and purposes of TPACK.	TPACK, a synthesized form of knowledge that supports the effective use of technology within specific subject domains, has been recognized as a unique type of knowledge required for effective use of technology in classroom teaching. TPACK centers on the nuanced interactions among content knowledge, technological knowledge, and pedagogical knowledge. Using the TPACK framework allows researchers to predict and identify approaches for promoting educational technology and improving teacher education.
	Review studies utilizing the TPACK framework to develop pre-service teachers' technology integration in teaching practices.	Methods aimed at helping pre-service teachers develop TPACK comprehension can be found either through the content-specific teaching methods courses that introduce pre-service teachers to teaching theories and methods or through educational technology courses. Noticeably, engaging pre-service teachers in a series of design tasks which involved their technological, content, and pedagogical decisions has been recognized as a promising method for developing teachers' TPACK competencies in the reviewed studies.
	Review literature grounded on TPACK to measure pre-service teachers' TPACK development.	Researchers often used qualitative, quantitative, or mixed-methods to investigate teachers' development of TPACK in teacher education programs. Self-report survey measures, which included multiple sub-scales of TPACK, are one of the

		most commonly used methods for accessing participants' TPACK.
	Synthesize studies to connect TPACK with CT in pre-service teacher training. Bridge the connections among computing tools, content knowledge, and pedagogical decisions related to pre-service teachers' CT implementation.	The TPACK framework describes how TK contributed to teachers' overall TPACK. TPACK provides a useful framework for studying teacher knowledge in relation to CT because computational tools frequently play a central role in CT-related concepts and practices. Moreover, utilizing the TPACK framework enables researchers to probe pre-service teachers' understanding of how CT-related concepts, computing tools, and practices (TK-CT) can be combined with disciplinary content (CK), and pedagogical strategies (PK) to achieve effective technology integration in CT-infused contexts (TPACK-CT).

Theme 1: The Evolution of CT in Education.

CT is rooted in the field of computer science (CS) and was defined as *algorithmic thinking* tracing back to 1950s and 1960s (Denning & Freeman, 2009). With the development of CS, CT gradually expanded from merely addressing *algorithmic thinking* to covering *algorithmic thinking*, *problem-solving,* and *computational method* (Barr & Stephenson, 2011). To date, the definition of CT has not yet been unified in a variety of communities (Voogt, Fisser, Good, Mishra, & Yadav, 2015). However, it has been ubiquitously recognized as a problem-solving process which involves both computing and cognitive domains (Anderson, 2016; Google, 2015; Wing, 2014). Whilst the search for a unanimous definition of CT is still in progress, the recognition of it as an essential

skill for 21st-century citizens has led to CT being introduced widely into K-12 education (Angeli et al., 2016; NRC, 2012; Voogt et al., 2015; Wing, 2006).

Seymour Papert (1980) is considered to be the innovator who brought CT into the grade school learning environment, as he proposed the *theory of computation* about using a computer programming tool to enable students to analyze and explain mathematical problems (DeSchryver & Yadav, 2015; Papert, 1980). Similar to Papert's vision of computation, Vee provided a closer definition towards CT but used the term *computational literacy* (Vee, 2013, as cited in Mannila et al., 2014). Vee (2013) formulated computational literacy as an ability with which people can break down a complex phenomenon and provide steps to carry out solutions through readable codes. Papert and Vee provided early glimpses of CT being related to the problem-solving process. Their articulation of CT was almost identical to CT's definitions in CS as algorithmic thinking and problem solving (Mannila et al., 2014).

Wing's (2006) pioneering work indicated that CT is not merely a concept restricted to CS, but also a fundamental analytical skill for everyone: "(it is) a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use" (p. 33). Wing's (2006) definition of CT consisted of three constructs: a) *algorithm*: step-by-step procedural instructions; b) *abstraction*: generalizing and transforming the problem-solving process to similar situations; and c) *automation*: automating problem solutions through simulations. Wing's significant statement rekindled CT development and implementation within the field of education. In 2010, Cuny, Snyder, and Wing updated the definition of CT by providing a more thorough explanation: "(CT is) the thought processes involved in formulating problems and their

solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (as cited in Wing, 2014, p.1).

In 2010, the National Research Council echoed Wing's advocacy of advancing CT for *all* students by defining CT as a cognitive skill that "the average person in modern society is expected to possess" (p. 13). This report expanded the definition of CT by extracting essential CT concepts from CS, viewing CT as "a range of concepts, applications, tools and skill sets", "as language and the importance of programming", "as the automation of abstractions" and "as a cognitive tool"; moreover, the report recognized the role of CT in "contexts without programming a computer" (NRC, 2010). Corresponding with the NRC report, the Common Core State Standards (CCSS) and Next Generation Science Standards (NGSS) dovetailed the definition of CT into content areas including mathematics, literacy, and science (CCSS, 2010a, 2010b; NGSS, 2013). For instance, the National Center for Women & Information Technology (NCWIT) identified particular CT practice from the CCSS in literacy including abstraction and data ("CSTA K-12 Computer Science Standards: Mapped to Common Core State Standards", 2013). Moreover, the NGSS views CT as one of the eight scientific and engineering practices and expects science learners to "develop and use models" and "use mathematics and computational thinking" (NGSS, 2013).

Similarly, the CSTA and the ISTE collaborated with leaders from the educational and industrial fields to develop a more concise definition of CT concepts suitable for use in K-12 education. These concepts demonstrated skills, which are not merely in line with CS or other STEM subjects, but also relate to other disciplines. The seven CT concepts include: a) problem decomposition: "breaking down complex problems into more

manageable parts"; b) algorithmic thinking: "using a precise sequence of steps or instructions to solve problems"; c) abstraction: "reducing complexity to define a main idea/applying abstraction to develop models of natural or artificial phenomena"; d) data collection, analysis, and representation: "accessing, evaluating and representing data using words, images or models"; e) automation: "using digital tools to automate solutions"; f) parallelization: "making things happen at the same time/organizing resources to simultaneously carry out tasks that help achieve a common goal"; and g) simulation: "representing a process" (CSTA & ISTE, 2011).

Recently, the ISTE Standards for Students emphasized the need of our younger generations to develop CT skills to understand and solve problems by leveraging strategies and technology (ISTE, 2016). Moreover, the ISTE Standards (2016) specified key CT skills that students need to acquire, which included formulating problems, abstraction, algorithmic thinking, data, and automation. More importantly, the ISTE Standards stressed the importance of situating CT within today's prevailing technology context by expecting students to "formulate problem definitions suited for technology-assisted methods" (p. 2).

Undoubtedly, it is crucial for the next generation to acquire and enact CT, which encompasses knowledge and skillsets necessary to thrive in the digital era (Barr & Stephenson, 2011; NRC, 2010). Therefore, educational policies and organizations have been advocating the pressing need for equipping our younger generation with CT competencies, by updating the expectations to further its integration into K-12 settings (Angeli et al., 2016; Barr & Stephenson, 2011; CCSS, 2010a, 2010b; NGSS, 2013; NRC, 2012).

Theme 2: Introducing CT in Education: Approaches, Rewards and Issues.

Embedding CT into high school CS curricula. Since CS is viewed as the precursor of CT, one way to introduce CT into the field of education is through CS curricular implementation. For instance, the Computer Science Principles Project was developed to "reach a wide and diverse audience of students and share with them the deep and rich intellectual and practical contributions of computing" (Astrachan & Briggs, 2012, p. 1). The CS Principles curriculum specified a set of CT practices based on the seven "Big Ideas" of computing which contain abstraction, data, programming and so forth (Astrachan & Briggs, 2012). In 2013, Grover and Pea analyzed the literature and summarized nine CT elements that have broadly comprised CS curricula: a) abstraction and pattern generalizations; b) systematic processing of information; c) symbol systems and representations; d) algorithmic notions of flow of control; e) structured problem decomposition; f) iterative, recursive, and parallel thinking; g) conditional logic; h) efficiency and performance constraints; and i) debugging and systematic error detection. Many CS curricula placed an emphasis on using programming to introduce and evaluate students' CT because programming has been viewed as "a fundamental skill of CS," as well as "a demonstration of computational competencies" (Astrachan & Briggs, 2012, p. 40). However, such CS curricula were found to be either CS concentrated or to be more approachable to mature learners (e.g., high school) who have already acquired the prerequisite CS knowledge (Grover & Pea, 2013; Mannila et al., 2014).

Emerging research studies indicated that CT should be taught early and often in order to prepare our students to adequately develop critical thinking and problem-solving skills (Jonassen, 1995; Lu & Fletcher, 2009). Therefore, new initiatives have been put

forth to expose younger learners in the context of computing, specifically through programming activities (e.g., programming and robotics) and curricula, such as Exploring Computer Science (ECS) (Code.org, 2017; College Board, 2014). Programming has been viewed as a common method to expose K-8 students to CT through designing games, digital stories, robotics and so forth (Lye & Koh, 2014). Accordingly, constructionism has become a common pedagogical strategy used by researchers and educators alike to guide students to create personally meaningful artifacts within a programming context in order to promote their CT development (Buss & Gramboa, 2017; Lye & Koh, 2014).

Promoting CT in K-8 through constructionism. Constructionism was introduced by Seymour Papert after his inspiring observation of an art classroom where students crafted their products through socially engaging with each other and using an iterative design process (Halverson & Sheridan, 2014; Kafai, 2006; Papert & Harel, 1991). Such an interesting observation spurred Papert to foresee the promising future of engaging learners into creating and sharing ideas through the process of artifact production (Halverson & Sheridan, 2014; Papert & Harel, 1991). Papert (1991) further elaborated the definition of constructionism to include pedagogical principles with an emphasis on teaching and learning. Specifically, constructionism emphasizes an iterative learning phenomenon (e.g., the design process), which allows learners to create personalized and meaningful projects (e.g., programming products) in relation to CT concepts through tools or technology. In this regard, the use of tools and technology shapes what learners can do, think, and know about a product that synthesizes ideas (Hughes et al., 2016). Reciprocally, learners' thoughts and ideas also have effects on how

tools should be used, adapted or structured (Brennan & Resnick, 2012; Kafai & Burke, 2013).

Moreover, constructionism stresses the role of learning communities, which means that learners do not construct their knowledge alone; instead, they construct knowledge by interacting with others within their community (Resnick et al., 2009). Sharing personally meaningful products through interaction and collaboration with other community members generates learners' metacognitive process to reflect and revise their projects and therefore to promote meaningful learning (Kafai, 2006; Noss & Hoyles, 2006). In summary, constructionism-oriented learning environments provided learners with opportunities to construct knowledge of computational concepts and dispositions through making meaningful products and social interaction (Brennan, 2015; Kafai & Burke, 2013).

Constructionism is often used as the theoretical grounding for studies examining younger learners in computational work as they develop CT knowledge and skillsets. Resnick et al. (2009) investigated how students developed CT by examining their programming projects and interactions with other people within a learning community. Learners used a "low floor and high ceiling" (easy for novices to get started with programming but also can be challenging enough for advanced learners to create complex programming projects) programming tool, Scratch, to design and create personalized and meaningful artifacts, such as stories and games. Moreover, these Scratch learners ("Scratchers") were observed to be socialized in the Scratch community through different forms such as collaboration, remixing projects, commenting on projects, and other interactions with others. In this specific programming learning environment, which was

designed based on constructionism, Scratchers were observed to adequately develop computing skills as they were "constantly borrowing, adapting, and building on one another's ideas, images, and programs" with other community members (p. 65).

Similarly, Falloon (2016) examined how young children developed CT and cognitive skills through programming from Scratch. Engaging children through computational activities that required both computational knowledge and verbal interactions with peers was found to promote students' cognitive dimensions of programming. Such dynamic phenomena grounded in constructionist approaches open different types of learning opportunities to students since they were able to collaborate with others within the Scratch community to share, reflect, revise and remix their projects, and to develop CT skills, such as algorithmic thinking and problem decomposition (Brennan & Resnick, 2012; Kafai, Desai, Peppler, Chiu & Moya, 2008).

Issues for expanding CT in K-8. Reviewed studies grounded in constructionism were often situated in a programming context. More commonly, these studies merely sought to improve learners' CT competencies related to CS concepts, such as loops and events (Brennan & Resnick, 2012). Besides being situated in the CS context, integrating CT into other disciplines has been progressively acknowledged. For instance, CT can be fostered and supported by other concepts beyond CS, such as mathematics. In Papert's early work, Logo, a programming software, was used for learners to create geometric shapes and relevant projects to further students' mathematical learning through the process of construction (Papert & Harel, 1991). Similarly, Hughes and colleagues (2016) connected learners' CT with mathematical learning within the construction process and proposed that CT can be infused through learners' mathematical learning. In fact, CT

covers wider foundations to help students process information and tasks in more systematic and efficient ways (Barr & Stephenson, 2011; CSTA & ISTE, 2010). Merely exposing students to CT through learning programming leads to misconceptions that CT is equivalent to programming (Sadik et al., 2017). As a result, more efforts are needed to bridge the chasm between CT and other disciplines in K-8 including literacy, science and social studies (Mouza et al., 2017b). Infusing CT with other disciplines allows learners to recognize and investigate linkages among CT knowledge, discipline knowledge, and real-life applications (Weinberg, 2013). In conclusion, CT could be embedded into K-8 classrooms across disciplines from science to the humanities to benefit students with varied interests. For example, CT could be implemented through scientific investigations, digital storytelling (Lee, Martin, & Apone, 2014), making movements (Rode, Weibert, Marshall, Aal, von Rekowski, El Mimouni, & Booker, 2015), and representations of algorithm design (Mannila et al., 2014).

Theme 3. Preparing Teachers for Infusing CT in K-8.

Promoting CT in K-8 settings relies on teachers' ability to integrate CT-related knowledge and skills within their content area (Barr & Stephenson, 2011; CSTA & ISTE, 2011; DeSchryver & Yadav, 2015; Yadav et al., 2014). However, this is challenging because few teachers have the knowledge and skills to embed CT in school curricula (Code.org, 2017). Therefore, increasing efforts have been invested to equip teachers with knowledge and skills needed to infuse CT into their classrooms. These efforts can be divided into two categories: Professional development (PD) for in-service teachers (Croff, 2017) and training for pre-service teachers in teacher education programs (Mouza et al., 2017b).

CT training for in-service teachers. PD experiences have been commonly used to provide training to in-service teachers. Current research indicates that providing in-service teachers training in CT concepts and related pedagogical strategies has been found to be effective. Toikkanen and Leinonen (2017) studied Finnish elementary teachers' perceptions about programming after they participated in a massive open online course (MOOC). The online course introduced 500 elementary teachers to basic CT and programming concepts, along with a combination of teaching practices and pedagogical thinking. Through partial participants' feedback and responses to a questionnaire, the study's preliminary findings showed that teachers who completed the course appeared to recognize the importance and benefits of implementing programming concepts into different content areas. Moreover, they were more confident in enacting programming concepts due to the fact that they had practice using the Scratch programming tool. Similarly, Buss and Gamboa (2017) studied how in-service teachers developed an understanding of core CT concepts through a PD program that introduced participants to gaming and robotics tools that addressed CS aspects. Through survey results and classroom observations, most participants demonstrated an increased understanding of and more positive attitudes towards CT. Moreover, guided and open-ended instruction were commonly observed as participants taught CT concepts in their classroom settings.

In conclusion, providing in-service teachers with short-term PD is found to be beneficial in equipping them with CT skills. However, the long-term effects of such PD modules in changing teachers' enactment regarding computing still need to be investigated.

CT training for pre-service teachers. A promising step for successfully integrating CT into K-8 education is to help future teachers develop an understanding of CT and its connection to their curricular context (Yadav et al., 2016, 2017). To date, various approaches have been utilized to prepare pre-service teachers to embed CT into their future classrooms including in teacher education courses involving educational psychology, educational technology, and teaching methods as well as adding a computer education course to traditional teacher education courses.

One way to equip pre-service teachers with CT knowledge and skills that could be further implemented in their future classroom is to introduce CT through their required teaching training courses. Yadav et al. (2014) introduced pre-service teachers to CT through a one-week module in an introductory educational psychology course. Bringing together experts from both education and computer science, this week-long learning module on CT was designed to introduce CT concepts connected to daily life to prepare the pre-service teachers to enact CT principles into their subject content. The ultimate goal of the module was to have pre-service teachers combine knowledge of the content, pedagogy, and resources in relation to CT for lesson planning (Yadav et al., 2014). Throughout this one-week module, pre-service teachers were presented with a CT definition and were guided to envision CT integration into their future classrooms. Using a quasi-experimental design, this study concluded that the week-long module significantly improved preservice teachers' CT understanding and willingness to implement CT in their future classrooms. Mouza and colleagues (2017b) introduced a redesigned educational technology course, which embedded CT concepts within computing technology to K-8 pre-service teachers. Computing tools were introduced to

the pre-service teachers in conjunction with pedagogical practices. With a mixed methods design, results of the study showed pre-service teachers' understanding of CT. However, the pre-service teachers demonstrated various levels of CT implementation with technology in their CT lesson plan designs.

Furthermore, recent research efforts have sought to connect pre-service teachers' CT implementation within certain teaching methods courses required in specific teacher education programs. Jaipal-Jamani and Angeli (2017) introduced robotics construction kits into a science methods course for pre-service teachers as a way to develop their self-efficacy, science learning, and CT. The robotics construction kits were designed to introduce CT processes to K-12 students through programming (Jaipal-Jamani & Angeli, 2017). Moreover, the authors argued that features of robotics construction kits could be connected to science topics, such as motion, force, etc. Hence, a robotics intervention embedded in a 12-week science methods course was designed to introduce CT concepts about teaching science topics for pre-service teachers. The study results revealed that engaging pre-service teachers in learning robotics positively influenced their beliefs to teach with robotics, their science knowledge, and their CT skills (Jaipal-Jamani & Angeli, 2017).

Similarly, a study conducted by Lehtinen, et al. (2016) aimed to connect CT concepts with science education. Lehtinen and colleagues (2016) designed an intervention, which scaffolded pre-service teachers to foster understanding of various simulation topics in science through a technology software. Moreover, participants were required to integrate practices of simulation into classroom teaching (Lehtinen et al., 2016). The study results show that pre-service teachers' knowledge related to technology

was statistically significantly correlate to their disposition toward integrating simulations in their teaching practice. Besides situating CT in the context of science education, Hughes and colleagues (2016) envisioned a promising way of using computational tools, the Arduino and the Chibitronics, to promote mathematics learning in the classroom. In the authors' proposal, teachers could use such computational tools to infuse CT and mathematics concepts into classroom teaching.

Another way to equip pre-service teachers with CT knowledge and skills involves exposing them to programming knowledge in addition to enrolling in their teacher education courses. Sadik et al. (2017) studied the CT understanding of 12 pre-service teachers who enrolled in an add-on computer education license program. The participants were required to develop a two-hour instructional project to help 5th-grade students learn about CT concepts through programming. Moreover, the participants were paired up and implemented two activities selected from their project into different 5th-grade classrooms. This study gathered a series of participants' course products (e.g., initial proposals, papers, etc.) as they developed a complete instructional package. With a single-case design, this study demonstrated that involving teachers in the process of developing CT-infused lessons appears to have positive effects on promoting teachers to foster deeper and more accurate CT understanding and implementation (Sadik et al., 2017). Sadik et al. (2017) also recognized that pre-service teachers commonly viewed CT as a problem-solving strategy; however, some participants held misconceptions, considering CT as an algorithm and therefore providing faulty approaches to integrating CT into the classroom in the lesson plan.

Likewise, Cetin (2016) examined pre-service teachers' understandings and attitudes towards basic programming concepts. A total of 56 pre-service teachers participated in a 6-week learning module; 28 participants were in the control group who received traditional instruction in learning programming and 28 were in the experimental group. The experimental group was introduced to the Scratch-based instruction in which participants were encouraged to construct computing artifacts through using Scratch. Data included participants' achievement tests, practice tests, and computer programming attitude scales as quantitative data and conducted semi-structured interviews as qualitative data. The quasi-experiment study results indicated that participants from the experimental group had a better understanding of basic computing concepts. Moreover, the Scratch-based instruction was endorsed by the pre-service teachers as it provided a more meaningful and comprehensive learning environment for pre-service teachers in developing programming competencies. This study revealed that having pre-service teachers experiment with the creation of games and animations through Scratch allowed them to transfer and connect CT related concepts to teaching practices (Cetin, 2016).

Although the above studies recognized the importance of connecting pre-service teachers' programming competencies with teaching practices, they did not demonstrate the connection between programming within specific disciplinary context in K-8. Bean Weese, Feldhausen, and Bell (2015) introduced pre-service teachers to a two-hour intervention, which connected Scratch programming with a content area (e.g., music, arts and math). Data were collected through a Teachers' Self-Efficacy in CT survey. The study results showed that participants' self-efficacy in utilizing programming and CT in their future teaching endeavors increased after the intervention. The study revealed that

situating CT concepts (programming) within disciplinary areas could be a promising approach for fostering pre-service teachers understanding and implementation of CT (Bean et al., 2015).

Establishing research gaps in teacher learning of CT. Policies and initiatives have underscored the necessity of preparing teachers to integrate CT into the classroom; however, only a limited number of studies have examined the disciplinary and pedagogical approaches needed for pre-service teachers to acquire knowledge and skills needed for implementation of CT in the classroom (Cetin, 2016; Lye & Koh, 2014; Mouza et al., 2017b; Smith, 2016; Yadav et al, 2016, 2017). Among these studies, introducing CT concepts to pre-service teachers has been found crucial to engaging them with CT ideas and further CT implementation (Croff, 2017; Yadav et al., 2014). Moreover, several studies had involved pre-service teachers in design tasks, which allowed them to develop CT lessons (Sadik et al., 2017; Stephenson, Gal-Ezer, Haberman, & Verno, 2005). These studies showed that effective learning modules, such as engaging pre-service teachers into tackling CT concepts and envisioning its applications into teaching practice, held promise for implementing CT in the classrooms.

Bower and Falkner (2015) designed a learning module for pre-service teachers who did not have any CT background. Their pilot study of 44 pre-service teachers found that most participants had misconceptions about CT, such as viewing it as the use of technology to solve problems. This misconception led to participants asserting that implementing CT into classrooms was to simply have students use technology during class. Accordingly, Bower and Falkner (2015) suggested that providing pre-service teachers with CT learning opportunities should encompass the following three

components: developing their CT pedagogical capabilities, developing their technological understanding, and developing CT content knowledge. Further, they suggested that the conceptual framework of TPACK become embedded in the design of the learning environment to better facilitate pre-service teachers' CT practices.

Likewise, Yadav et al. (2017) distributed an open-ended survey to 95 pre-service teachers to probe how they defined CT and their views on how it could be implemented. This study found that participants demonstrated various levels of CT understanding: on one hand, participants were able to foresee CT as a promising way to enhance students' learning; on the other hand, participants held only a superficial understanding of CT concepts and oversimplified CT implementation in K-12 classroom settings. Additionally, most pre-service teachers inaccurately thought that the generic use of computers or technology could promote CT implementation. Thus, Yadav and colleagues suggested to "transform educational technology toward computing education and to structure courses to engage pre-service teachers in computational thinking tools and ideas" (p. 218).

Using technology as a starting point to introduce pre-service teachers to CT concepts and practices has been frequently addressed in studies related to promoting pre-service teachers' CT understanding and implementation. Given the prevalence of technology in today's classrooms, one way to infuse CT into K-8 is to equip teachers with the knowledge and skills needed to weave CT ideas and tools into their everyday pedagogical activities (Angeli et al., 2016; Bower & Falkner, 2005; Lye & Koh, 2014; Mouza et al., 2017b; Prieto-Rodriguez & Berretta, 2014; Yadav et al., 2017). Although the above-reviewed studies were not situated in the context of the TPACK framework,

they also revealed that TPACK could be a promising starting point to instill CT into teaching practice through increasing teachers' technological knowledge in computational tools.

Therefore, I concluded that a holistic and systematic way to formulate CT training programs for pre-service teachers is through the TPACK framework. In particular, TPACK specifies the knowledge base required for pre-service teachers to effectively integrate technology into teaching practices.

Secondly, although the reviewed studies aimed at helping teachers become competent in CT integration, only one study was found to present examples that demonstrate pre-service teachers' teaching practices in relation to CT (Mouza et al., 2017b). More specifically, few studies presented evidence to illustrate pre-service teachers' learning trajectory in relation to CT implementation. However, the importance of employing longitudinal work to examine the effects of teacher preparation on pre-service teachers' implementation of CT in their classroom practices is currently recognized (Sadik et al., 2017). Hence, I proposed that evidence is needed to instantiate pre-service teachers' trajectories during their participation in teacher preparation, as well as after their participation to identify actual CT implementation.

Finally, from a methodological standpoint, reviewed studies regarding CT preparation for pre-service teachers mainly utilized quantitative methods, especially surveys that measured pre-service teachers' changes in knowledge and attitudes related to CT concepts and implementation. Qualitative studies related to pre-service teachers' CT development during a teacher preparation program were commonly found in a few mixed-method research studies. However, current research methods regarding pre-service

teachers' CT development are emerging; more rigorous research designs are therefore needed on this topic. Furthermore, as Yadav et al. (2017) suggested, using interviews to probe pre-service teachers' in-depth understanding of CT could help researchers conceptualize their CT developing concepts. One recommendation from Polly, McGee and Sullivan (2010) is to develop in-depth case studies in order to capture participants' perceptions and experiences of the integration of technology.

Thus, I concluded that there is a need to incorporate a rigorous mixed-method study design, which utilizes rich quantitative and qualitative data to provide ample evidence that illustrates pre-service teachers' CT development and implementation connected with their content and pedagogical decisions in a technological context.

Theme 4. TPACK Framework as a Conceptual Lens.

TPACK components and purposes. Teaching is a complex process; teachers need not only to carefully plan what to teach but also to delicately consider how to maximize instructional effectiveness (Kennedy, 2005). Moreover, as different types of educational technology have been widely adopted in today's classrooms, teachers have more options to deliver content and support instruction (Gray, Thomas, & Lewis, 2010). Beginning in 2009, the CCSS initiatives focused on the role of technology in students' learning in English language arts and mathematics. Likewise, NGSS (2013) emphasized that engineering, technology, and science influence society and the natural world. Such educational standards reflect that effective teaching in today's classroom requires teachers to understand how to use technology, in addition to mastering sufficient content knowledge (CCSS, 2010a, 2010b). Consequently, the TPACK framework was developed

to outline the knowledge base for teachers' understanding of technology integration required to achieve "effective teaching with technology" (Mishra & Koehler, 2006).

The TPACK framework is based on Shulman's (1987) influential work on articulating teachers' *pedagogical content knowledge* (PCK). Shulman presented a description of a knowledge base for teaching which argued that effective teaching encapsulates teachers' profound subject-matter knowledge with appropriate pedagogical approaches. Based on Shulman's foundation of teacher knowledge, numerous pioneers in education undertook further efforts to define teachers' knowledge related to technology integration (Angeli & Valanides, 2005; Mishra & Koehler, 2006). Angeli and Valanides (2005) proposed the information and communication technology pedagogical content knowledge (ICT-PCK) framework, emphasizing six components of teacher knowledge: content knowledge, learner knowledge, pedagogical knowledge, technical knowledge, context knowledge, and TPCK (Angeli & Valanides, 2005; Angeli et al., 2016). In this transformative model, technology, pedagogy, and content were viewed as a unique body of knowledge (Angeli & Valanides, 2005).

Concurrently, Mishra and Koehler (2006) proposed an alternative framework which conceptualized TPACK as an integrative body of knowledge defined by the intersections among technology, content, and pedagogy. One of the most significant commonalities between the ICT-PCK (Angeli & Valanides, 2005) and the TPACK (Mishra & Koehler, 2006) frameworks is that both depict different knowledge components as intertwining as a cohesive whole, placing TPACK/TPCK as the overarching trait to indicate that teachers should be able to comprehend and negotiate the interactive relationship among content, technology and pedagogy (Angeli & Valanidis,

2005; Giannakos, Doukakis, Pappas, Adamopoulos, & Giannopoulou, 2015; Mishra & Koehler, 2006). To date, the TPACK model has been considered to better reflect the interdependence of each of the knowledge components (Giannakos et al., 2015).

The TPACK framework (Figure 2.1) outlines three core components of teachers' knowledge: content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK). Moreover, the TPACK framework demonstrates the interactions between and among these components, which are pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and TPACK. Furthermore, the TPACK framework placed contextual factors as an important element in relation to all knowledge components within the theoretical ground (Mishra & Koehler, 2006).

The definitions of CK, PK and TK are concrete and can be easily understood; however, the definitions of PCK, TCK, TPK, and TPACK needed to be carefully defined, since some scholars raised concerns about how to set clear boundaries between these constructs (Angeli & Valanides, 2009; Archambault & Barnett, 2010; Graham, 2011).

The PCK construct within the TPACK framework is identical to Shulman's PCK, which means that teachers need crucial knowledge of how to teach and how to learn (Shulman, 1987). For instance, teachers should understand the importance of obtaining students' prior knowledge in learning new content. Moreover, teachers also need to understand how to plan lessons and assess students' learning progress (Harris, Mishra, & Koehler, 2009). The concept of TCK shares similarities with PCK but emphasizes teachers' understanding of how the use of technology can enhance subject-matter learning (Harris et al., 2009; Mishra & Koehler, 2006). Since there is such a variety of

technology, developing TPK requires teachers to acquire TCK to understand the benefits and limitations of integrating certain technologies into curricula (Voogt et al., 2015). Finally, TPACK, a synthesized form of knowledge that supports effective use of technology within specific subject domains, demonstrates multiple interactions among content, pedagogical, technological, and contextual knowledge. TPACK reflects and emphasizes that effective teaching with technology integration requires continually creating, maintaining, and re-establishing a dynamic equilibrium among all components (Angeli & Valanides, 2009; Mishra & Koehler, 2006; Voogt et al., 2015).

The main purpose of the TPACK framework is to "assist the development of better techniques for discovering and describing how technology-related professional knowledge is implemented and instantiated in practice" (Koehler & Mishra, 2009, p. 67). Since TPACK presents different constructs that influence effective teaching with technology integration in teaching practice, it provides researchers with "concepts and terminologies" to understand complex teaching phenomena (Koehler, Shin, & Mishra, 2012). Furthermore, using the TPACK framework allows researchers to predict and identify approaches for promoting educational technology and improving teacher education. Finally, as Koehler and colleagues (2012) stated, researchers can develop applications based on the TPACK framework to ensure that there is greater alignment between theory and design. TPACK has been recognized as a unique type of knowledge required for effective use of technology in classroom teaching. However, there are different recommendations on how to develop and assess TPACK in teacher learning.

Methods for developing teachers' TPACK. One method for helping teachers develop TPACK comprehension is through content-specific teaching methods courses

that introduce pre-service teachers to teaching theories and methods, as well as through student teaching/field experiences embedded in teaching education programs (Hofer & Grandgenett, 2012; Mouza, Karchmer-Klein, Nandakumar, Ozden, & Hu, 2014). Most often, this method utilized a transformative model grounded in Shulman's PCK framework and aimed to facilitate pre-service teachers' development of solid content and pedagogical knowledge, which can be transformed to the development of TPACK (Koehler, Mishra, Kereluik, Shin, & Graham, 2014).

For instance, Jang, and Chen (2010) developed a three-stage model including TPACK comprehension, observation, and reflection to assist pre-service teachers to transform PCK to TPACK in a science teaching method course. Initially, pre-service teachers observed how technology could be integrated into classrooms through peer coaching. Later on, pre-service teachers were required to design and implement a 30-minute mini co-teaching technology integration activity. In this study, pre-service teachers' TPACK was driven by their content and pedagogical decisions and they were able to model their final technology integration lesson (Jang & Chen, 2010). Similarly, Niess (2005) illustrated a multi-dimensional science and mathematics program, which targeted promoting pre-service teachers' teaching and learning with technology. In addition to enhancing pre-service teachers' PCK development, the program emphasized promoting pre-service teachers' connections among content, pedagogy, and technology. In particular, pre-service teachers were guided to plan a sequence of lessons to integrate technology in curricula (Niess, 2005).

Another method is to help pre-service teachers develop TPACK through educational technology courses. Studies suggested different approaches to facilitating

teacher learners' abilities to integrate technology effectively, including through observation of modeling by other educators and engaging prospective teachers in implementing technology (Pamuk, 2012). Such courses introduced pre-service teachers with TPK then gradually scaffolded them to develop TPACK (Hofer & Grandgenett, 2012). For instance, Koh and Divaharan (2011) proposed a three-phase TPACK-Developing Instructional Model to support teachers' TPACK development. The first phase was to "foster acceptance" which helped pre-service teachers recognize and accept the pedagogical utility of certain technology. The second phase was "technological proficiency and pedagogical modeling" which helped develop pre-service teachers' technological knowledge along with TCK and TPK. Finally, pre-service teachers were at the stage of "pedagogical application" in which they were given opportunities to formulate TPACK through design technology-integrated lessons for a selected lesson topic.

Jimoyiannis (2010) examined science teachers' development of TPACK through designing a series of authentic activities -- learning activities that could be implemented into classroom settings. In particular, pre-service teachers were given problem-based scenarios and were guided through an iterative design process as they planned, evaluated, and revised their lesson products. The study results suggested that teachers developed meaningful technological pedagogical science knowledge and appeared interested in adopting this framework in their classrooms.

Hofer and Grandgenett (2012) studied pre-service teachers' TPACK development through an educational technology course situated in a master's program. This educational technology course introduced pre-service teachers to a variety of technology

that supported curriculum-based teaching and learning. In addition to completing a set of course assignments, which helped pre-service teachers connect technology and their teaching discipline, the pre-service teachers were required to design a technology-integrated lesson plan. Hofer and Grandgenett (2012) found that participants' TPK and TPACK were significantly developed upon completion of the course.

Mouza et al. (2014) examined how participants applied TPACK learned from an educational technology course in classroom practice. In this study, pre-service teachers attended a designed educational technology course and applied what they learned in class into their field placement. The field placement involved pre-service teachers working with classroom teachers to design and implement technology into different subject areas. As the authors stated, combining method courses with field experience provides participants opportunities to gain technological knowledge and knowledge related to other domains within the TPACK framework. With the use of the TPACK survey and performance assessment, Mouza et al. (2014) found that an integrated instructional approach that provides pre-service teachers with a variety of TPACK models can help promote their development of TPACK. In particular, pre-service teachers' knowledge about the affordances of technology, content, pedagogy, and context could be used instantaneously during this iterative instructional design process (Mouza et al., 2014).

In summary, two commonalities were identified between methods aimed at assisting pre-service teachers to effectively integrate technology into the classroom. First, the design rationale for effective TPACK learning modules was found to be in line with the TPACK development model proposed by Niess, Lee, Sadri, and Suharwoto (2006). The TPACK development model consisted of a five-stage sequential process: a)

recognizing (knowledge); b) accepting (persuasion); c) adapting (decision); d) exploring (implementation); and e) advancing (confirmation). This model has been adopted in various studies designed to provide teachers with TPACK competencies (Niess et al., 2009). In particular, these programs provided a series of learning activities, such as peer-coaching and microteaching, to assist pre-service teachers in progressively designing, reflecting on, and implementing technology in classroom settings. Notably, engaging pre-service teachers in a series of design tasks which involved their technological, content, and pedagogical decisions has been recognized as a promising method for developing teachers' TPACK competencies in the reviewed studies (Angeli & Valanides, 2009). In fact, involving pre-service teachers in design tasks enables researchers to understand their TPACK development and the relationships among knowledge of technology, content, and pedagogy (Graham, 2011; Koehler Mishra, & Yahya, 2007).

Methods for measuring teachers' TPACK. Researchers often used qualitative, quantitative, or mixed-methods to investigate teachers' development of TPACK in teacher education and professional development programs. Self-report survey measures, which included multiple sub-scales of TPACK, are one of the most commonly used methods for accessing participants' TPACK (Archambault & Barnett, 2010; Chai, Koh, Tsai, & Tan, 2011; Koehler et al. 2012). For instance, to examine how math teachers gain TPACK, Landry (2010) developed and validated a survey, which measures participants' knowledge of math content, pedagogy, and technology through a mixed method study design. The results showed that although math teachers acquired strong content and pedagogical knowledge, their TPK and TCK were relatively weak. Moreover, Barron, Kemker, Harmes, and Kalaydjian (2003) examined teachers' use of technology in math

and science classrooms. After surveying 2,156 teachers in a school district, chi-square tests showed that teachers in different school levels used technology differently: elementary teachers were twice as likely to use computers as problem-solving or decision-making tools than high school teachers. Similarly, Giannakos and coauthors (2015) surveyed more than 600 computer science teachers about their TPACK understanding. The Pearson Correlation Coefficients showed that teachers' TPK had the strongest correlations with their TPACK while their TK had the weakest correlation with TPACK. However, these studies only administered the survey at one time and did not control important factors, which may have influenced the study findings, including selection bias.

Other measures such as open-ended questionnaires, performance assessments, interviews, and observations were also utilized in research studies to measure participants' TPACK (Koh & Divaharan, 2011; Mouza & Karchmer-Klein, 2013; Mouza et al., 2014; Tondeur et al., 2012). For example, Jimoyiannis (2010) interviewed science teachers about their thoughts after they participated in a TPACK PD. However, detailed information about the interview protocol was not provided nor were these data triangulated with other data to validate qualitative findings. In contrast, multiple sources of data were obtained in other studies. For instance, Hofer and Grandgenett (2012) utilized self-report surveys, structured reflections, and instructional plans to show how pre-service teachers' TPK and TPACK were developed throughout an 11-month master's program. Similarly, Mouza et al. (2014) used pre-service teachers' survey responses and performance assessments to probe pre-service teachers' longitudinal TPACK

development. None of these studies, however, focused specifically on TPACK in relation to CT.

Bridging TPACK with teachers' CT implementation. The TPACK framework demonstrates how TK contributes to teachers' overall TPACK (Mishra & Koehler, 2006). In essence, teachers' beliefs about technology can influence their preferences about using it in their teaching practices (Chen, 2010). However, teachers' beliefs and knowledge are always intertwined – increasing teachers' knowledge about technology (TK) and how to integrate it into teaching practices (TPACK) can result in changes to teachers' beliefs in the usefulness of technology (Abbitt, 2011; Jaipal-Jamani & Angeli, 2017; Pajares, 1992, as cited in Lehtinen et al., 2016). Since the TPACK framework helped researchers identify types of knowledge that can ameliorate teaching CT in classroom settings, it can offer a potential lens for designing learning experiences that promote teachers' knowledge of CT and how to integrate it with teaching practices (Angeli et al., 2016; Bower & Falkner, 2015). It can also provide a means for analyzing that knowledge. To date, the TPACK framework has become an analytical lens for studying teachers' knowledge in relation to teaching specific content (e.g., mathematics, science, CS) with technology. Literature that deliberately explores the relationship between TPACK and CT for all teachers in K-8 is sparse.

Yadav and colleagues (2014) explored pedagogical approaches for teaching CT in K-12 settings, which were found to be indistinguishable from the TPACK framework. Although Yadav and colleagues (2014) did not particularly address the role of TPACK in relation to CT in their study design, evidence drawn from the module activities and measures elucidated that pre-service teachers' CT development and enactment were

affected by their content, pedagogy and technology/resources used throughout the lesson planning process (Yadav et al., 2014). Moreover, a series of studies were found to implicitly apply the TPACK framework to promote teachers' CT within specific content areas by exposing them to computational technology (Hughes et al., 2016; Jaipal-Jamani & Angeli, 2017). In this instance, TPACK could be utilized to help researchers select and design essential features in intervention and training sections for teachers to connect CT and teaching practices.

TPACK was first explicitly used by Angeli and colleagues to help identify what knowledge teachers should acquire to effectively promote CT in K-6 (Angeli et al., 2016). The authors developed a CT framework in which CT concepts and skills were related to CS. Furthermore, they argued that teachers should be prepared to foster a group of knowledge to implement the CT curriculum. This group of knowledge was situated within TPACK because technology serves in the central role of the CS domain as an independent construct as well as a means to achieve teaching and learning goals (Angeli et al., 2016). In this study, each knowledge component was tied to CT specifically from the CS discipline.

Lehtinen et al. (2016) utilized the TPACK framework to probe pre-service teachers' beliefs and attitudes towards simulations. Simulation, one of the CT constructs, was not only identified in the CT definitions by CSTA and ISTE (2010) but was also addressed in NGSS (2010) as one of the eight scientific and engineering practices associated with CT: "developing and using models" and "using mathematics and computational thinking". In this study, TPACK was used as a measurement to identify how pre-service teachers' teaching practices related to using simulation technology or

other types of technology in science education. Although this study used the TPACK approach to measure teaching practice in relation to science and simulation, the role of CT was not clearly addressed and measured.

Recently, Mouza and colleagues (2017b) started to specify the construct of TPACK in relation to CT, focusing on what all teachers need to know and be able to do in order to use CT as a means for exploring disciplinary content (e.g., math, science, literacy, etc.). In particular, this study shed light on pre-service teachers' ability to understand CT by using technology. At the end of the study, Mouza et al. (2017b) advanced the term TPACK-CT to represent teacher knowledge that promotes CT implementation in specific contexts.

In conclusion, recent studies aimed at equipping K-8 teachers with CT knowledge and skills implicitly or explicitly tie in with TPACK in light of teaching teachers how CT tools (i.e., TK) can be used to infuse CT into different disciplines (Hughes et al., 2016; Jaipal-Jamani & Angeli, 2017; Lehtinen et al., 2016). According to the literature, a promising approach to developing TPACK competencies focuses on engaging pre-service teachers with instructional design tasks (Angeli & Valanides, 2009). Moreover, engaging pre-service teachers in the process of instructional design enables researchers to probe participants' TPACK development and decisions (Graham et al., 2011). Similar to instructional design, emerging research indicates that involving teachers in lesson planning helps them gain an understanding related to the implementation of CT into the curriculum (Yadav et al., 2017).

Therefore, TPACK provides a useful framework for studying teacher knowledge in relation to CT because computational tools frequently play a central role in CT-related

concepts and practices (Mouza et al., 2017b). Since TPACK specified the knowledge base for effective teaching with technology, it also serves as a guideline to help researchers examine the development of teachers' practices regarding computing technology (Angeli et al., 2016). Thus, using the TPACK framework enables researchers to probe pre-service teachers' understanding of how CT-related concepts, computing tools, and practices (TK-CT) can be combined with disciplinary content (CK) and pedagogical strategies (PK) to achieve effective technology integration in CT-infused contexts (TPACK-CT).

Restating the use of TPACK in promoting pre-service teachers' CT implementation. In this study, I examine how pre-service teachers incorporate CT in K-8 settings throughout their participation in an educational technology course. More importantly, I exemplify pre-service teachers' CT developing trajectories during and after their participation in the educational technology course. As in prior work (Mouza et al., 2017b), the construct of TPACK is used in two ways: as a framework for guiding the design of the educational technology course, and as an analytic lens for examining pre-service teachers' learning outcomes illustrated in course products. More specifically, this dissertation addresses the construct of TPACK in relation to CT (Figure 2.1), which focuses on pre-service teachers' understanding of how CT-related concepts, computing tools, and practices (TK-CT) can be combined with disciplinary content (CK) and pedagogical strategies (PK) to achieve effective technology integration in CT-infused contexts (TPACK-CT).

Teachers' acquisition of technology-specific TK serves as a foundation for considering its pedagogical uses (Koh & Divaharan, 2011). In this work, computing tools

were identified based on three core principles proposed by Repenning, Basawapatna, and Escherle (2017). These core principles corresponded to three stages of the CT process: a) problem formulation, which means that CT tools should "empower users to explore representations without the need to code" (p. 292); b) solution expression, which means that computational tools should "allow users to create relevant computational artifacts such as games and simulations" (p. 292) ; and c) solution execution and evaluation, which mean that CT tools should "help users comprehend and validate computational artifacts" with "accessible execution visualization mechanisms" (p. 293). In particular, pre-service teachers were firs introduced to computing tools which could be used in conjunction with content areas (TK-CT). Simultaneously, the course engaged pre-service teachers in a series of lesson planning activities that required their technological, content and pedagogical decisions (TPACK-CT).

In addition to guiding the design of the course, the TPACK framework was used as an analytic lens to evaluate pre-service teachers' knowledge of CT implementation. In particular, TPACK outlines essential constructs that could be utilized to assess teachers' TPACK development (Graham, 2011). Consequently, this dissertation referred to the TPACK constructs particularly TK-CT and TPACK-CT to evaluate how pre-service teachers demonstrate TPACK-CT development throughout their course-related CT products and interviews.

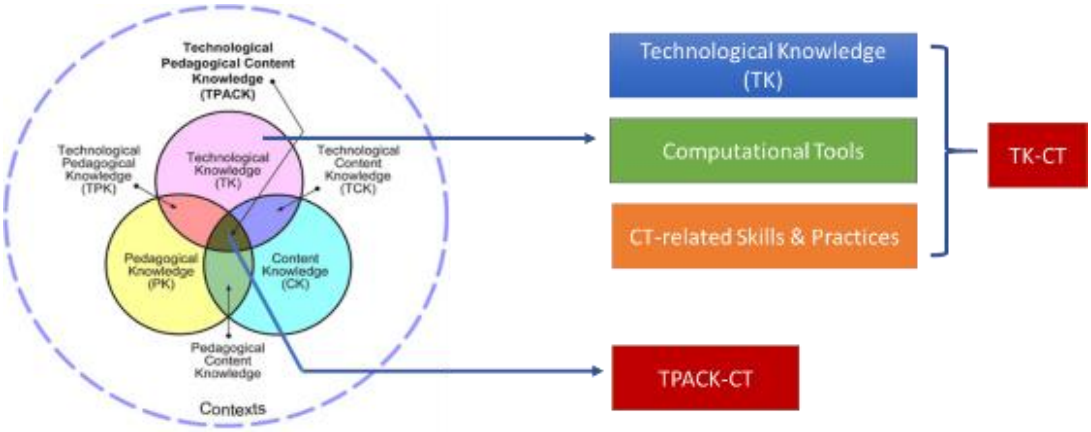


Figure 2.1 TPACK-CT framework (Based on Mishra & Koehler, 2006).

Chapter 3

METHODOLOGY

Chapter Overview

The purpose of this dissertation is to examine how pre-service teachers develop CT knowledge and skills, including its application to school curricula and everyday pedagogical activities. Moreover, this dissertation aims at exemplifying how CT was conceptualized and integrated by pre-service teachers in the context of technology. According to these two overarching study purposes, I utilized a two-phase mixed-methods research design following the core characteristics of mixed-methods research (Creswell & Plano-Clark, 2017).

Phase I focused on examining pre-service teachers' understanding of CT-related concepts, computing tools, and practices and perceptions of CT implementation in K-8 curricula. A mixed-methods convergent study design was used to address three research questions:

1. How does participation in a redesigned educational technology course influence pre-service teachers' understanding of CT as illustrated in pre and post survey data? (Quantitative Research Question)

2. How do pre-service teachers perceive the implementation of CT into K-8 core content areas, including the role of technology during CT implementation? (Qualitative Research Question)
3. To what extent do pre-service teachers' perceptions of CT implementation as illustrated in the qualitative results relate to their CT understanding as illustrated in the quantitative survey results? (Mixed-Methods Research Question)

Phase II of the study extended the Phase I investigation by further exemplifying pre-service teachers' understanding of CT concepts, selection of CT tools, and consideration of content and pedagogical decisions in relation to CT. With this purpose in mind, I utilized a case study approach embedded within a mixed-methods explanatory research framework. Case studies are a special type of qualitative work, which portray a bounded phenomenon, such as a program or an individual (Hatch, 2002). Using a case study approach enables researchers to answer the "how" and "why" questions in order to obtain an in-depth understanding of the phenomenon (Baxter & Jack, 2008). For instance, Srisawasdi (2012) used the case study method to understand pre-service teachers' transformation of TPACK. In particular, this study portrayed three pre-service teachers' TPACK transformation by collecting and examining two TPACK learning modules of using information and communication technology within their teaching practice. Researchers who used a qualitative case study method to study pre-service teachers' TPACK development often collected a range of qualitative data such as lesson plans, observations, interviews, and so forth (Tondeur et al., 2012). However, the limitations of

qualitative case studies have been recognized in the academic community. Such limitations include researchers' justification for the selection of case study approaches (Hyett, Kenny, & Dickson-Swift, 2014) and whether researchers could maximally interpret the results from solely using a single technique (Palak & Walls, 2009).

To overcome some of the limitations associated with qualitative case studies, researchers have employed mixed-methods approaches to measuring pre-service teachers' TPACK development. Palak and Walls (2009), for instance, used a sequential/explanatory mixed-method design to study pre-service teachers' beliefs related to technology integration. Their design contained a quantitative strand followed by a qualitative strand. The quantitative strand was used to help the researchers determine two pairs of cases with extreme differences in teachers' beliefs. Once case study participants were selected, the researchers collected multiple sources for each case, including interviews, lesson plans, and reflections. Finally, the study integrated all data to interpret pre-service teachers' beliefs and technology practices (Palak & Walls, 2009). Similarly, Kopcha, Ottenbreit-Leftwich, Jung, and Baser (2014) used a mixed-methods case study design to measure pre-service teachers' TPACK development. In this study, quantitative and qualitative data were collected and merged into a joint display for the description of cases. Both of these studies illustrate the advantages of using a mixed-methods study design for investigating pre-service teachers' TPACK. First, using a sequential/explanatory mixed-methods case study approach provided the researchers with rationales to justify the selection for case studies. Second, mixed-methods approaches illustrated procedures for integrating various data to generate focal cases. Strategies for

integrating various forms of data included using a joint display, which enables the researcher to compare similarities and differences in ways that highlighted integrated findings (Creswell & Plano-Clark, 2017).

Accordingly, Phase II employed a sequential/explanatory mixed methods case study design to analyze participants' lesson plan scores (quantitative strand), followed by an examination of their course-related CT products (e.g., lesson plans and blog posts) and individual interview data. Ultimately, these data sources were integrated to generate in-depth and valid cases that represent pre-service teachers' CT trajectories. Three research questions were developed to guide the mixed methods study in Phase II:

4. What trajectory of TPACK-CT do pre-service teachers exhibit during their participation in the redesigned educational technology course? (Quantitative Research Question)
5. How is TPACK-CT represented in pre-service teachers' course-related CT products? (Qualitative Research Question)
6. What are the similarities and differences across the different TPACK-CT trajectories? (Mixed-Methods Research Question)

Researcher Positionality

In this mixed-methods study, the qualitative strand played an important role in helping me obtain detailed and nuanced understandings about pre-service teachers' CT through the context of technology integration. More specifically, I collected and analyzed substantial qualitative data such as the pre-service teachers' course products and interviews. Therefore, the research process has been influenced by my positionality as a

qualitative researcher. Positionality is shaped by an individual's identity and personal experience and influenced researchers' decisions in determining research questions and selecting methodologies (Foote & Bartell, 2011; Rose, 1997). My prior experience working with pre-service and in-service teachers positioned me to be the "insider" as a co-instructor in a course and as a former pre-service teacher (Bourke, 2014). With knowledge of the context and the population being studied, I drew on my insider status when I had conversations with pre-service teachers about their thoughts on how CT could be implemented in the classroom. In my conversations with the pre-service teachers during the interviews, my insider stance positioned me to probe questions which might relate to participants' decisions about CT implementation but was not mentioned/recognized by the participants. On the other hand, my status as an "insider" shifted to an "outsider" at several time points during the research process such as while I observed how pre-service teachers approach the concept of CT in the class without participating (Moore, 2012). Moreover, I also positioned myself to be an "outsider" as a way of managing my subjectivity and contributing towards the trustworthiness of the data (Greene, 2014).

Study Description

Context. The study is situated in a four-year undergraduate teacher education program in a Mid-Atlantic University in the United States. Graduates of the program are eligible for both elementary (K-5) and middle school (6-8) teacher certification. The program curriculum is divided into three areas: a) general studies courses, which help develop subject matter knowledge; b) professional studies courses (e.g., methods), which

prepare pre-service teachers for their future classroom; and c) concentration courses, which help develop expertise in a middle school content area. Additionally, the program curriculum is designed to provide pre-service teachers with a range of field experiences in a variety of classroom settings. These experiences culminate with student teaching.

Redesigned Educational Technology Course Description. Integrating Technology in Education is a required course for all pre-service teachers, taken in their junior or senior year, in which they receive an extensive field experience by co-operating with classroom teachers in designing and teaching lessons. This 15-week course introduces technologies available for use in classroom content areas, pedagogical considerations with these technologies, and teaching and learning practices that combine the use of technologies with content and pedagogy. To infuse CT concepts and practices into the teacher education program, my affiliate research group had redesigned this course to support the development of pre-service teachers' use of CT-related concepts and tools, as well as to promote their CT practices within specific disciplines and pedagogy. The main components of this redesigned course included introducing CT concepts (e.g., CT concepts from the CSTA and ISTE standards) and computing technologies available for use in the classroom (e.g., interactive whiteboard/Smartboard). More importantly, course activities aimed to actively engage pre-service teachers in the design, application, and reflection of lesson materials that embed CT and computing technologies in content-area instruction. In particular, we grounded our design on the 5-step curricular-based technology integration approach by Harris and Hofer (2009) to scaffold pre-service teachers approach and develop CT-infused lessons in the context of

technology. Table 3.1 below presents the main learning modules containing computing tools, associated activities and CT supported skills covered by this course.

Table 3.1 Main Learning Modules of the Redesigned Educational Technology Course.

Week	**CT-related Technology**	**Activity & Related Practices (CT Concepts, CT Tools & CT Practices)**	**CT Supported Skills**
2-3	Interactive Whiteboards	Identify two interactive whiteboard resources that support key CT skills: *Modeling* (e.g., a resource that can be used to represent a phenomenon such as prey and predator relationship); *Sequencing* (a resource that could be used to sequence events); *Data* (e.g., a resource that could be used to represent data such as a graph); and *Sorting* (e.g., a resource that could be used to organize information)	Modeling Abstraction Algorithmic Thinking Data & Sorting
4-6	Programming Hour of Code Scratch	*CS unplugged* (activity done without computers to introduce algorithms) *Hour of Code*: Completion of a Grades 2-8 activity *Introduction to Scratch Programming*: Scratch is an object oriented programming language Review lessons that support the use of Scratch: ScratchED Design of a learning activity in a content area that involves Scratch Programming/Reflection	Algorithmic Thinking Problem Decomposition Modeling Abstraction
7-8	Concept Mapping Tools	Design of a learning activity that uses concept mapping in a content area to support student development of CT skills, such as decompose a mathematical problem, model abstraction (e.g., life cycle of a butterfly), sequence events in a story or plan essay execution.	Problem Decomposition Algorithmic Thinking Modeling Abstraction
10	Data	Introduction to Internet Research including use of keywords, boolean	Problem Decomposition Modeling

		logic and operators and evaluation of online content	Abstraction
11-12	Collaboration tools	Select and read an article on multiple approaches to developing CT: board games, robotics, programming. Use of a collaboration tool to present the reading to classmates.	Problem Decomposition Algorithmic Thinking Modeling Abstraction

Each assignment or course product requires pre-service teachers to integrate CT by using computing technologies to support content learning. For instance, pre-service teachers need to incorporate technologies in relation to CT (TK-CT), make connections to a learning objective related to a content area, and select pedagogical strategies in conjunction with CT implementation (TPACK-CT). Table 3.2 presents the course products related to developing pre-service teachers' TK-CT and TPACK-CT. Moreover, to effectively facilitate pre-service teachers' learning, the course instructor and the teaching assistants provided immediate feedback to each assignment consistently throughout the course.

Table 3.2 Course Products of the Redesigned Educational Technology Course.

Assignment Order	**CT-related Technology**	**Product Type**	**Course Product Description**
1	Smartboard Resources	Collaborative Blog Post	Pre-service teachers selected two of the following categories and identified one resource from the Smart Exchange that was of high quality for their selected CT categories: CATEGORY – Modeling: A resource that could be used to represent a phenomenon (e.g., life cycle, prey and predatory, cause and effect, etc.) CATEGORY – Sequencing: A resource that could be used to create a sequence of events (e.g., sequence of solving a math problem, story sequence, historical timeline, etc.)

			CATEGORY – Data: A resource that could be used to represent numerical data (e.g., record, enter, graph or visualize numeric data, etc.) or a resource that could be used to represent qualitative data (e.g., story elements, character analysis, etc.). CATEGORY – Sorting: A resource that could be used to sort, order, compare and organize information (living and non-living things, human body parts, etc.).
2	Technology Inventory	Collaborative Blog Post	Pre-service teachers reported information about the technology available in their classroom. As they completed the inventory, they were required to start thinking about the kinds of computer activities which they would consider implementing in their practicum classroom.
3	Models of Technology Integration	Collaborative Blog Post	Pre-service teachers evaluated two examples of Technology Integration listed in the Technology Integration Matrix (http://fcit.usf.edu/matrix/matrix.php). They were required to situate their evaluation within the TPACK framework.
4	Hour of Code Reflection	Collaborative Blog Post	Pre-service teachers reflected upon their Hour of Code learning experience by specifying which course they tried out from Code.org, their thoughts about the learning modules and suggestions about the Code.org courses.
5	CT Lesson Idea	Instructional Design Task (Hypothetical Lesson Plan)	Pre-service teachers developed lesson plans that incorporated Scratch programming within a curriculum content area. To accomplish this goal, they first examined user-created projects available on the Scratch community that fitted their curricular goals. Subsequently, they examined a variety of lesson plans through the ScratchEd community, an online publicly available forum where educators exchange resources, pose questions and share experiences to broaden the integration of Scratch into core curricular contexts. Finally, they identified a learning goal within a content area of their choice (e.g., science, mathematics, social studies, English) and developed a lesson plan that integrates programming with curriculum content. To scaffold lesson development, pre-service

			teachers were provided with a series of prompts aligned with the TPACK framework (see Harris, Grandgennet, & Hofer, 2010), including (a) planning (e.g., Consider the pedagogical decisions you'll need to make to develop this lesson idea. How will you introduce Scratch to your students? What activity types will students engage with to learn the concept? In what ways will you assess student learning?); and (b) reflection (e.g., How will programming help your students achieve the identified learning goal? How will the lesson support the development of students' CT skills? What was your experience with Scratch?).
6	Concept Mapping and CT	Instructional Design Task (Hypothetical Lesson Plan)	Pre-service teachers were subsequently asked to identify a learning goal within a content area of their choice (e.g., science, mathematics, social studies, English) and develop a lesson plan that integrates concept mapping in a core curricular area. To scaffold lesson development, a series of planning and reflection prompts was again provided that paralleled those of the programming activity.
7	Web 2.0 Tools and CT	Collaborative Blog Post	Pre-service teachers utilized a Web 2.0 tool to develop a multimodal presentation reflecting upon CT.
8	CT Case	Instructional Design Task (Authentic Lesson Plan)	The case development project progressed incrementally through stages that allowed participants to implement and reflect on their own lessons that supported the development of CT knowledge and skills among school students. Participants were allowed to implement one of the lessons designed throughout their participation in the Technology Integration course (e.g., programming, concept mapping) or design a new lesson that integrated technology with content and pedagogy aimed at supporting students' CT knowledge and skills. The culminating component of the project was a reflective case report of approximately 1,000 words written in response to several prompts. Specifically, each case report was divided into two sections: (a) case narrative (e.g., How did you introduce the lesson to students? What

			happened during the actual implementation of your lesson?), and (b) case reflection (e.g., How did the lesson support the development of students' CT skills? What are two things you will remember about this lesson for future planning?).

Phase I Study

Research design. Phase I of the study employed a mixed-method convergent design which allowed the author to examine both quantitative and qualitative data to articulate the in-depth meaning of pre-service teachers' understanding and perception of CT (Creswell & Plano-Clark, 2017). Figure 3.1 below presents an overall convergent design diagram for this study.

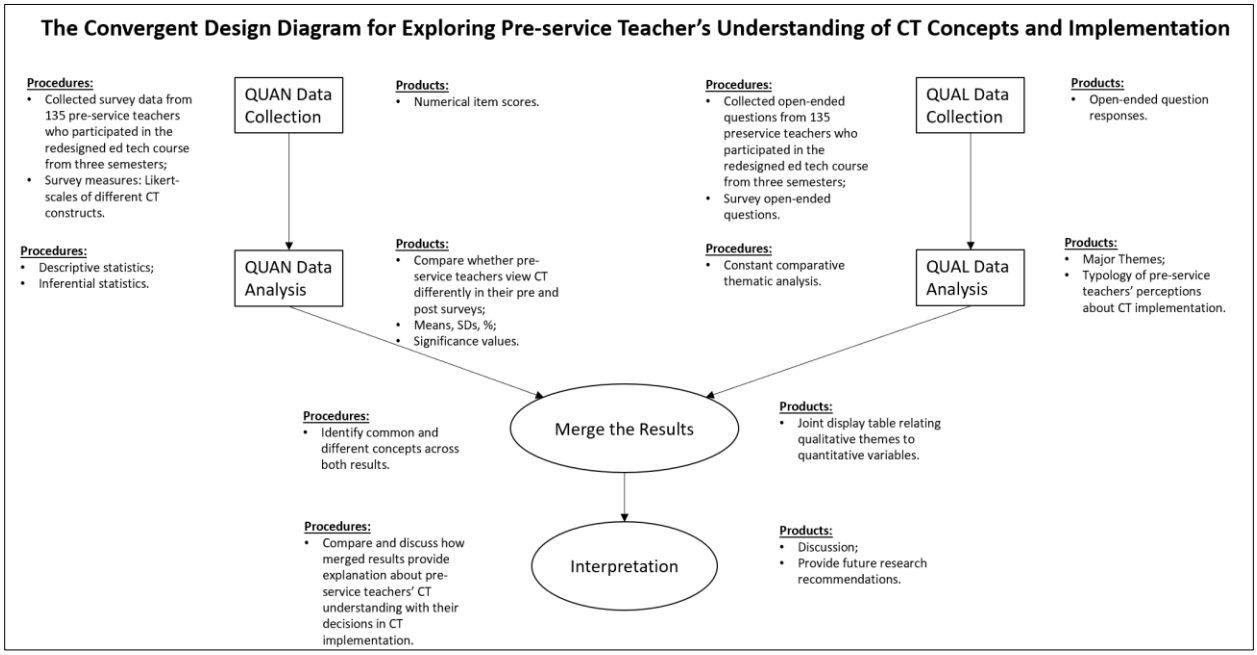


Figure 3.1 The Convergent Design Diagram for the Phase I Study

Participants. Phase I study participants included all pre-service teachers who enrolled in the redesigned educational technology course for three consecutive semesters.

Most pre-service teachers enrolled in this course majored in Elementary Education. Additionally, some of these pre-service teachers chose a concentration which prepared them for certification in a second area: English as a second language, middle school English, middle school math, middle school science, middle school social studies, and special education. Participation in the study was totally voluntary. Participants' course grades were not affected if they chose not to participate in this study. Consent forms and questionnaires were distributed to the pre-service teachers by two research assistants, so the course instructor did not know who participated in the study. In total, 135 out of 145 pre-service teachers agreed to participate in this study. In this representative sample, ninety-three percent were female. The majority of the participants were in their junior year in college.

Data sources and data collection. Phase I of the study used a CT survey and three open-ended questions to measure pre-service teachers' understanding of CT concepts and CT implementation in K-8 curricula. These two instruments were combined into a single CT Questionnaire.

Survey Items (Quantitative Strand). Phase I of the study utilized a CT survey developed and validated in two research studies (Mouza et al., 2017b; Yadav et al., 2014). The Cronbach's alphas (> .70) from both studies indicated that the items within the survey have good internal consistency (Mouza et al., 2017b; Nunnally, 1978; Yadav et al., 2014). The survey instrument contained 26 Likert-scale items in relation to CT constructs, including a) definition (e.g., computational thinking is understanding how computers work); b) comfort (e.g., I can learn to understand computing concepts); c)

interest (e.g., I will voluntarily take computing courses if I were given the opportunity); d) use in the classroom (e.g., CT can be integrated into the classroom); e) career/future use (e.g., Having background knowledge and understanding of computer science is valuable in and of itself); and f) knowledge and beliefs (e.g., I can use existing lesson plans that take advantage of CT tools and approaches in my classroom).

Open-ended Questions (Qualitative Strand). In addition to the 26 Likert-scale survey items, three open-ended questions were included in this study (Mouza et al., 2017b; Yadav et al., 2014): a) What do you think the term Computational Thinking means? b) Do you think Computational Thinking can be integrated into the classroom? If yes, how would you implement Computational Thinking into your future classroom? If no, why do you think Computational Thinking cannot be integrated into the classroom? and c) How can technologies be used to help develop school students' Computational Thinking skills?

On the first day of the course each semester, participants were asked to fill out the pre-questionnaire. Participants rated their agreement from "1" (strongly disagree) to "4" (strongly agree) for each survey item and typed their responses for all open-ended questions. On the last day of the course, participants were asked to complete the post-questionnaire with the exact same question items as in the pre-questionnaire. All participants completed the questionnaire electronically through the Qualtrics system.

Data analysis. Quantitative and qualitative data were analyzed separately. Survey results were analyzed using a paired t-test. Additionally, effect sizes were presented to quantify the extent of the difference between pre- and post-survey data (Cohen, 1988).

Pre- and post-responses to the open-ended questions were analyzed using the constant comparative method (Hatch, 2002). The author coded each response first and then subsequently combined similar codes into categories (Saldaña, 2015). Some responses were assigned more than one code since participants provided more than one idea throughout their answers. Finally, categories from each analysis, which indicated relevant concepts, were combined into themes. Figure 3.2 presents the hierarchical relationships among themes, categories, and codes.

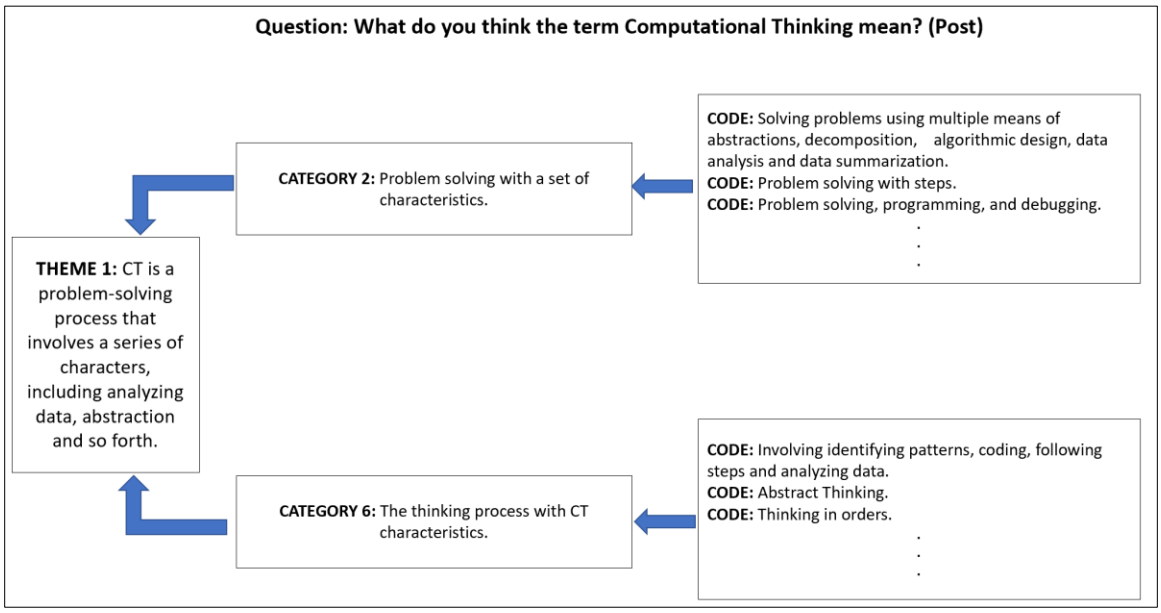


Figure 3.2 Visual Demonstration of Relationships among Themes, Categories, and Codes.

Integration Analysis of Quantitative and Qualitative Data. I first looked for salient information across quantitative and qualitative data, such as significant gains, as well as themes, by creating a joint display table (Creswell & Plano-Clark, 2017). To decide which information to present in the joint display table, I selected themes from the

qualitative results and three corresponding CT constructs from the quantitative results. The qualitative results for each open-ended question are presented as themes instead of categories. According to the streamlined codes-to-theory model presented by Saldaña (2015), some categories which contain clusters of coded data could be further compared and consolidated toward a thematic and conceptual level. In particular, Saldaña (2015) used the term "theme" to represent the refinements after merging such categories. Therefore, I compared and consolidated the categories from the qualitative results to further define potential themes during the integration analysis of quantitative and qualitative data. After doing such a comparison, I determined in what ways the results confirmed, disconfirmed or expanded each other. Finally, I provided an interpretation of how the integration of the qualitative and quantitative results contributed to answering how pre-service teachers' perception of CT implementation relates to their CT understanding.

Phase II Study

Research design. Phase II of the study employed an explanatory mixed methods case study design (Creswell & Plano-Clark, 2017). As illustrated in Figure 3.3, I first collected and analyzed the quantitative data from the participants. Results of the quantitative strand informed my decisions in selecting participants for the qualitative case study. Utilizing a mixed-method comparative case study design allows researchers to generate more detailed and contextualized cases using both quantitative and qualitative methods (Creswell & Plano-Clark, 2017; Ivankova, 2014).

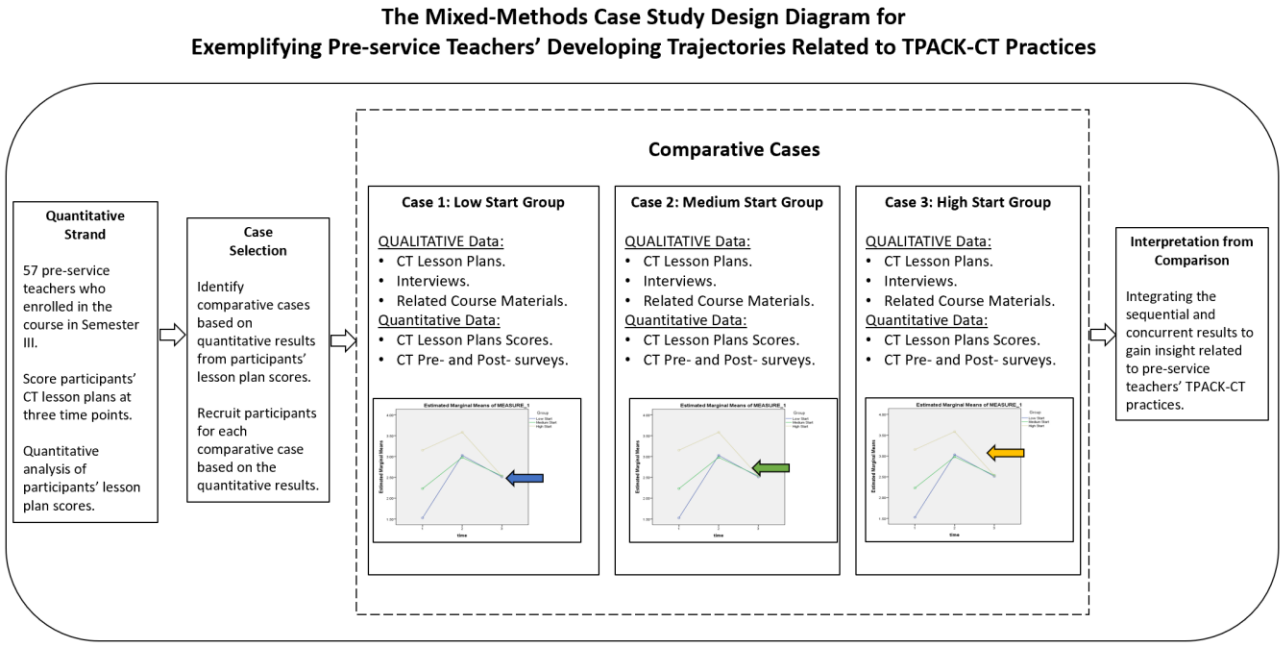


Figure 3.3 The Mixed Methods Case Study Design Diagram for the Phase II Study

Participants. Participants in the Phase II study were drawn from the Phase I sample (Figure 3.4 below). Considering that participants who enrolled in the course in Semester I and II had already graduated by the time this study entered Phase II, only the pre-service teachers enrolled in the course in Semester III were invited for the Phase II investigation. A total of 57 pre-service teachers who enrolled in the course in Semester III were invited. Among these participants, 94% were female. All participants were in their junior year. By the time of the study's data collection, all pre-service teachers were in their senior year, which was the student teaching phase of their program. All participants were invited to an individual interview. Eight pre-service teachers agreed to participate and scheduled an individual interview; only six successfully completed the interview. Each interview ranged from 35 to 50 minutes.

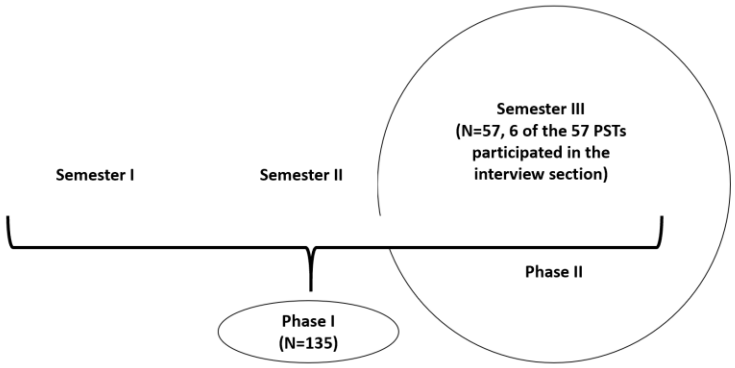


Figure 3.4 Participants in Phase I and Phase II

Table 3.3 presents an overview of the six interviewees' backgrounds. These pre-service teachers were in their third year when they participated in the redesigned technology course and entered their student teaching phase immediately afterward. They student taught at various settings including in elementary classrooms and middle school classrooms, depending on their concentrations in the teacher education program.

Table 3.3 Overview of Six Interviewees for the Phase II Study.

Name (Pseudonym)	**Concentration**	**Redesigned Technology Course Participation**		**Student Teaching Phase**		
		Year	**Field Placement**	**Year**	**Student Teaching Placement**	
					1st Semester	**2nd Semester**
Ella	Elementary Education + Middle School Math	Junior	3rd Grade	Senior	7th Grade Middle School Math	3rd Grade English
Sophie	Elementary Education + Middle School Math	Junior	4th Grade	Senior	7th Grade Middle School Math	5th Grade Core Subjects

Jane	Elementary Education + Special Education	Junior	4th Grade	Senior	1st Grade	3rd and 4th Grade Special Education
Lily	Elementary Education + Middle School Math	Junior	5th Grade	Senior	7th Grade Middle School Math	4th Grade Core Subjects
Kate	Elementary Education + Middle School Math	Junior	5th Grade	Senior	8th Grade Math	5th Grade Core Subjects
Amber	Elementary Education + English as a Second Language (ELA)	Junior	2nd Grade	Senior	4th Grade	4th Grade ELA

Data sources and data collection. The main data sources for Phase II were participants' CT lesson plans and follow-up interviews. The data collection timeline associated with the data sources is presented in Figure 3.5.

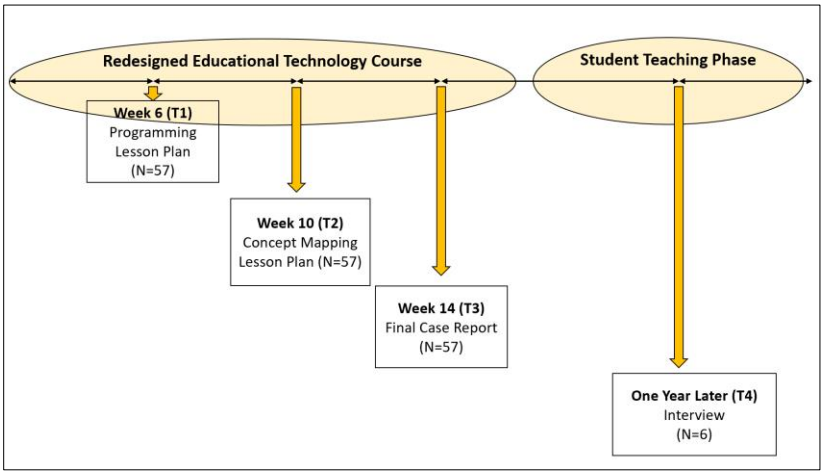


Figure 3.5 Data Collection Timeline of the Phase II Study.

A total of 171 (57*3) lesson plans were sequentially collected and subsequently scored. Pre-service teachers designed CT lesson plans throughout the course at three sequential time points (week 6, week 10 and week 14) throughout one semester, illustrated in Figure 3.5. In this dissertation, I used time points 1, 2 and 3 to represent the data collection order of the lesson products. Hypothetical lesson plans focusing on the integration of CT with content and pedagogy in participants' future classrooms were created at time points 1 and 2. Lesson plans created at time point 3, however, were actually implemented in the classroom during pre-service teachers' field experience. All assignments followed a consistent format; they first engaged pre-service teachers in developing knowledge and skills related to CT concepts and computing tools (TK-CT) and subsequently asked them to apply such knowledge in the context of disciplinary content and pedagogy (TPACK-CT).

At time point 1 (T1), pre-service teachers developed lesson plans that incorporated Scratch programming within a content area. To achieve this goal, they first examined and explored various resources (e.g., Scratch projects, teaching resources) through multiple platforms (e.g., ScratchEd community). Subsequently, they defined a content-specific learning goal and developed a lesson plan that integrated programming with curriculum content. Pre-service teachers were scaffolded with a series of prompts aligned with the TPACK framework (Harris et al., 2010) during their lesson planning process, including a) planning (e.g., Consider the pedagogical decisions you'll need to make to develop this lesson idea. How will you introduce Scratch to your students? What activity types will students engage with to learn the concept? In what ways will you

assess student learning?); and b) reflection (e.g., How will programming help your students achieve the identified learning goal? How will the lesson support the development of students' CT skills? What was your experience with Scratch?).

At time point 2 (T2), pre-service teachers developed lesson plans incorporating a concept mapping tool. After exploring various types of concept mapping tools, participants integrated concept mapping tools into a content area following the same procedures as the programming lesson plan design.

At time point 3 (T3), pre-service teachers could either choose to implement one of the lessons designed during their participation in the course (e.g., programming lesson, concept mapping lesson) or design and implement a new lesson that integrated technology within a content area to support students' CT knowledge and skills. The ultimate product was a reflective case report consisting of two components: a) case narrative (e.g., How did you introduce the lesson to students? What happened during the actual implementation of your lesson?); and b) case reflection (e.g., How did the lesson support the development of students' CT skills? What are two things you will remember about this lesson for future planning?).

Considering that data collected at time point 3 was the only source to reflect pre-service teachers' CT implementation in an authentic classroom setting, I decided to add an additional data source related to pre-service teachers' CT implementation in their teaching practice. By Phase II of the study, participants were in the student teaching phase of the teacher education program. In student teaching, pre-service teachers are fully engaged in a school context by designing and teaching lessons and getting involved in

school-wide activities throughout a full semester. Therefore, the fourth time point (T4) was created to administer a follow-up interview with the pre-service participants two semesters after the pre-service teachers completed the redesigned educational technology course.

Interviews in qualitative studies help researchers understand participants' experiences and the meanings they make of such experiences (Meister, 2010). Additionally, in-depth interviews encourage participants to explain their unique perspective on issues at hand (Hatch, 2002). Moreover, using interviews enables participants to report information about their beliefs and experiences (Steyn, 2006). According to Hatch (2002), effective questions should be opened-ended, clear, and generate answers related to the objectives of the research study. However, since interviews provide participants opportunities to freely express their thoughts and feelings (Poekert, 2011), good interviewers should have a sense of the sufficient amount of time needed to facilitate meaningful conversation (Hatch, 2002). In order to address this potential dilemma, creating an interview guide that aligns with the study framework is helpful (Meister, 2010). Therefore, an interview protocol was developed for the Phase II study. This interview protocol was created to probe the extent to which pre-service teachers implemented CT in their field placements, as well as to identify factors that supported or hindered their decisions for CT implementation in the classroom. In particular, the interview questions were designed to prompt pre-service teachers to provide examples of when they designed a CT-infused lesson plan in the context of technology integration.

The interview protocol contained three stages of questions. Stage 1 aimed to obtain an overall understanding of pre-service teachers' background. A sample question from Stage 1 is: "*Can you describe your current student teaching placement, including your role and responsibilities, subjects taught, available classroom technology, classroom procedures, student demographics, school contexts (urban, suburban or urban) and so forth?*" Stage II focused on probing pre-service teachers' decisions related to CT implementation in their classroom teaching. A sample question set of the Stage II interview questions is: "*Have you ever implemented any CT activities or lessons listed in your survey responses during your student teaching experience? What were the reasons that made you implement (not implement) these CT activities or lessons? What types of technology did you use to implement these CT related activities*?" For these interview questions, the interviewee was provided with his/her previous survey responses when he/she enrolled in the redesigned educational technology course. Stage III was to explore factors which affect pre-service teachers' decisions on implementing CT in their teaching practice. A sample question of the Stage III interview questions is: "*What are your concerns and foreseen challenges that will hold back your decision to implement CT-infused lessons into your classroom? (e.g., CT knowledge; confidence and comfort; classroom climate, technology, lack of support, etc.)*". A full interview protocol can be found in Appendix A.

Several procedures approved by the University of Delaware's Institutional Review Board were taken in order to conduct interviews with pre-service teachers (Appendix B). All participants were individually invited to participate in an interview

through email. The initial invitation email described the study purpose and the interview procedure (Appendix C). After sending the initial invitation, several reminders were sent to the pre-service teachers every two weeks. To recruit more participants, I also contacted the teacher education program coordinator to help distribute the invitation email to the pre-service teacher cohort.

Once a pre-service teacher contacted me to express his/her interest about participating the study, I first scheduled the interview date and time with him/her; all participants preferred to complete the interview by phone due to their intensive teaching schedule in the daytime. About one week prior to the scheduled interview, I provided the participant with a CT review package through email. This was done due to a concern that retrospective accounts can affect the trustworthiness of findings. The CT review package provided information to help pre-service teachers retrieve what they had learned from the redesigned educational technology course one year before. This CT review package included a CT explanation from the ISTE and CSTA standards, description and example of the previous course activity and the pre-service teacher's respective responses to three open-ended questions in their CT-post-survey (Appendix D). On the interview day, the participants sent me their signed consent form (Appendix E), which was provided along with their CT review package. Each interview was scheduled for 60 minutes. Each interview was audiotaped and transcribed immediately afterward.

Data Analysis. Quantitative data, which contained a total of one hundred and seventy-one lesson plans (N=171), were scored using a modified version of the Technology Integration Assessment Rubric, a valid and reliable instrument aligned with

the TPACK framework, which can be used to evaluate pre-service teachers' lesson plans (Harris at al., 2010). The rubric identifies four evaluation criteria which include: a) curriculum goals and technologies (e.g., computing tools and practices that support the development of CT knowledge and skills); b) instructional strategies and technology: using computing tools to support teaching and learning that fosters students' CT knowledge and skills; c) technology selection(s): compatibility with curriculum goals and instructional strategies; and d) fit: alignment of content, pedagogy, and computing tools to foster CT knowledge and skills. Each of the four criteria can receive a numerical score from 1 to 4. A score of 1 indicates failure in satisfying the criterion, while a score of 4 indicates full success in satisfying the criterion.

Inter-rater Agreement. To ensure the reliability of the scoring results, I enlisted help from a second coder, a graduate student in a relevant field who is familiar with both TPACK and CT. Prior to scoring these lesson plans, we scored a random sample of the lesson plans from previous semesters and this resulted in an 87% inter-rater reliability. We then discussed all discrepancies until a 100% agreement was reached. Subsequently, the second coder and I independently scored 18% of the data set for this study (10 out of 57 participants). The initial inter-rater reliability was calculated as 93% (90% at T1, 96% at T2 and 92% at T3). All discrepancies were discussed and remedied until a 100% agreement was reached. Finally, I scored the rest of the lesson plans.

With the finalized scoring results, pre-service teachers' T1 scores were categorized into three groups: Low Start, Medium Start, and High Start. The Low Start group (N=30) received scores below 2.0, the Medium Start (N=18) group received scores

between 2.1 to 2.9, while the High Start (N=9) group received scores above 3.0. Based on initial scores, lesson plan data were analyzed using repeated measures analysis of variance (ANOVA) to present trajectories among and within the three groups, followed by a one-way ANOVA performed at each time point to determine the mean differences among groups. A power analysis was also conducted.

After the quantitative analysis, which aimed at exploring the trajectories among all pre-service teachers in this study, I conducted an extended qualitative analysis to illustrate the TPACK-CT representations among these trajectory groups. Therefore, an analytical coding approach was developed to systematically analyze pre-service teachers' 171 lesson plans across three time points, as well as six interview transcriptions at the fourth time point. This analytical approach (Table 3.4) was executed through four iterative stages reflecting my coding decisions. The culminating component of this coding approach was to generate emerging evidence to represent three TPACK-CT trajectories. I used the NVivo 12 software and Microsoft Excel together to organize and analyze all the qualitative data.

Table 3.4 Qualitative Analysis Overview

Stage	**Purpose**	**Main Step**	**Main Source**	**Primary Coding Technique**	**Main Coding Product**
Stage I	Developing a Coding Foundation	Step 1	171 Lesson Plans (as a whole)	Open coding; Axial coding; Selective coding.	Categories and codes related to how participants planned and implemented CT-infused lessons, as well as their attitudes, reflections upon their CT implementation, and

					usage of computing technologies.
		Step 2	171 Lesson Plans (as a whole)	Comparing, contrasting and organizing categories and codes to develop themes.	Themes that were extracted from numerous categories and codes.
		Step 3	171 Lesson Plans (by sorting into different trajectory groups)	Categorizing lesson plans and their respective codes into trajectory groups.	Coding products for each trajectory group contained themes and their respective categories and codes related to the lesson plans.
Stage II	Developing Representative Cases	Step 1	6 Interviews	Template coding; Open coding.	Categories and codes related to how participants implemented CT in their classrooms.
		Step 2	Lesson plans, course - related products (technology inventory, blog posts), interview	Narrative approach; Comparing codes.	A holistic narrative developed for each representative case.
Stage III	Developing Trajectory Group Profiles	Step 1	Coding products of all the lessons within each trajectory group	Comparing, synthesizing and finalizing the coding products for each trajectory group.	Final Evidence related to the TPACK-CT representation within each trajectory group based on the lesson plans and case analyses for each group.
			Holistic narratives within each		

			trajectory group		
Stage IV	Comparing Trajectory Group Profiles	Step 1	Trajectory group profiles	Comparing and contrasting	Similarities and differences among all trajectory groups.

Stage I – Developing Coding Foundation: I first coded all the lesson plans from 57 pre-service teachers. The lesson plan coding process was executed in two main cycles. The coding procedures of the lesson plan data began with pre-coding, during which I read through all lesson plans at each time point and highlighted "codable moments" (Saldaña, 2015, p. 20). This process was subsequently enhanced by my first coding cycle, which employed an exploratory method (Saldaña, 2015). In the exploratory coding process, I simultaneously utilized the constant comparative method, which allowed me to compare and create new codes among the lesson plans at each time point (Glaser, 1965; Hatch, 2002). My coding process proceeded to the second analytic cycle after I believed myself to have obtained enough "segments of the data" (Saldaña, 2015, p. 236). In this coding process, I focused on clustering broad and discrete coding segments into analytical units, which were defined as categories. This dynamic coding stage allowed me to obtain a comprehensive understanding of the lesson plans designed at each time point. This analytical process generated codes and categories related to how pre-service teachers plan and reflect on their lesson plans. Subsequently, I sorted all the lesson plans along with their respective codes and categories into three trajectory groups. I reviewed and summarized the codes and categories at particular time points within each trajectory. The purpose of doing so was to organize the coding products into representing each trajectory

group. Table 3.5 below presents an example of one category and its codes related to the first theme.

Table 3.5 An Example of the Coding Category and Its Codes Related to the TPACK-CT Theme.

Theme	**Category**	**Code**	**Description**	**Example (PST No., Time Point)**
TPACK-CT	Category 1: CT Concept (Referring to specific CT practice that was defined by the lesson)	Problem Decomposition	Pre-service teachers' lesson plan or interview data related to decomposing problems or concepts into more manageable parts.	Students used the base ten blocks to decompose the numbers by their place values in order to solve addition and subtraction problems. (PST 16, T2)
		Algorithmic Thinking	Pre-service teachers' lesson plan or interview data related to using sequencing or steps to solve problems or to complete tasks.	Students planned a Scratch project step by step to present the battles of the Civil War. (PST 47, T1)
		Abstraction	Pre-service teachers' lesson plan or interview data related to applying abstraction to develop models or define main ideas.	Students summarized the main idea of a story and represented the main idea by creating a Scratch animation. (PST 32, T1)
		Data	Pre-service teachers' lesson plan or interview data related to accessing, evaluating, analyzing and representing data using words, images or models.	Students evaluated and represented data through an online research project. (PST 3, T3)
		Automation	Pre-service teachers' lesson plan or interview data related to using digital tools to automate solutions.	Students created a Metric Converter using Scratch (PST 10, T3).

		Parallelization	Pre-service teachers' lesson plan or interview data related to organizing resources simultaneously to carry out tasks that help achieve a common goal or make things happen at the same time.	No lesson plan targeted this practice at T1, T2 and T3. PST 41 envisioned having her students working in groups to conduct a scientific experiment. The process of how each group would collaborate to gather data to test a hypothesis is aligned with parallelization. (PST 41, T4)
		Simulation	Pre-service teachers' lesson plan or interview data related to representing a process.	Students represented the process of the water cycle using a concept mapping tool. (PST 12, T2)

Stage II – Developing Cases. I worked to develop cases to represent each trajectory group. The pre-service teachers who participated in the interview automatically became the representatives of their respective trajectory group. A total of eight pre-service teachers agreed to participate in the interviews, however, two pre-service teachers did not answer the phone at the scheduled time nor replied to my follow-up emails/phone calls. Therefore, a total of six pre-service teachers volunteered to complete the interviews. Based on the quantitative results, two of the six interviewees were categorized to the Low Start Group, two were in the Medium Start Group, and two were in the High Start Group (Table 3.6 below).

Table 3.6 Representative Cases for Each TPACK-CT Trajectory Group.

Group (Based on the quantitative results)	**Name**	**Concentration**	**Student Teaching Phase**		
			Year	**Student Teaching Placement**	
				Semester I	**Semester II (Interview Period)**
Low Start	Ella	Elementary Education + Middle School Math	Senior	7th Grade Middle School Math	3rd Grade English
	Sophie	Elementary Education + Middle School Math	Senior	7th Grade Middle School Math	5th Grade Core Subjects
Medium Start	Jane	Elementary Education + Special Education	Senior	1st Grade	3rd and 4th Grade Special Education
	Lily	Elementary Education + Middle School Math	Senior	7th Grade Middle School Math	4th Grade Core Subjects
High Start	Kate	Elementary Education + Middle School Math	Senior	8th Grade Math	5th Grade Core Subjects
	Amber	Elementary Education + English as a Second Language	Senior	4th Grade	4th Grade ELA

The interview data coding process started with a pre-coding cycle, which allowed me to obtain a general overview of the data. Subsequently, I employed a procedural method through which I developed an *a priori* coding scheme (see Table 3.7) from the literature based on the purpose of the work (Ambrosini, Bowman, & Collier, 2010; Saldaña, 2015). Throughout my coding process, I carefully refined and updated the a priori coding scheme, such as adding additional categories that were not included in the a

priori coding scheme. In the second coding cycle for the interview data, I carefully reviewed the data to refine and confirm the coding results.

Table 3.7 Coding Scheme for Analyzing the Interview Data.

Category	**Explanation**	**Literature Support**
CT Knowledge	Referring to pre-service teachers' CT knowledge of CT vocabularies.	Bower et al., 2017; Yadav et al., 2016
	Referring to pre-service teachers' CT knowledge of CT understanding and conceptualization.	
Computing Technology Knowledge	Pre-service teachers' selection of computing technology.	Angeli et al., 2017; Mouza, Nandakumar, Ozden & Karchmer-Klein, 2017a;
	Pre-service teachers' knowledge of computing technology.	
Methods to integrate CT into curriculum	Instructional Formats (Whole-class/Small group)	Bower et al., 2017; Israel et al., 2015
	Level of Explicit Instruction (Teacher-centered/Student-centered)	
Attitudes and Beliefs	Attitudes towards CT	Bower et al., 2017; Yadav et al., 2016; Mouza et a., 2017a
	Beliefs in Usefulness of CT	
	Beliefs related to Computing Technology	
TPACK-CT	Linking CT into content areas	

	Weaving pedagogical, content and technological decisions into implementing CT.	Israel et al., 2015; Mouza et al., 2017a
Supports for implementing CT	Professional development	Israel et al., 2015
	School/district-level supports	
Factors related to implementing CT into the classroom	Access to technology	Israel et al., 2015
	Access to computing technology	
	Access to expert support in the classroom	
	Computing access issues due to learners	
	Instructional time	
	Students' computing experience	

After creating the three trajectory groups based on lesson plan scores, I further examined the pre-service teachers' lesson plans and interviews with other supplementary data sources, which included their technology inventory report and two of the blog posts related to their experiences of learning about the Hour of Code and Smartboard usage (see Table 3.2 in Chapter 3). The purpose of doing so was to identify details related to pre-service teachers' TPACK-CT implementation throughout the course. In particular, I developed holistic analysis narratives (Kopcha et al., 2014) to depict pre-service teachers' TPACK-CT developmental process in detail. Six holistic narratives were developed based on pre-service teachers' course artifacts and interview data. A sample component of one participant's holistic analysis narrative is shown in Figure 3.6:

Holistic Analysis Narrative of Amber (Part I – During the Course Participation)

Context I: Rural School with working technologies. However, the school did not have a clear policy related to the use of technologies. Students received weekly special related to technologies. The classroom had Macbook (3), Smartboard (1) and Elmo document camera (1).

Blog Posts

Smartboard Resources. Amber identified four Smartboard resources (TK-CT) which could be integrated to promote second graders' understandings in CT concepts (e.g., modeling, sequencing, data, sorting) and content specific knowledge (e.g., social studies, science, math, etc.) (TPACK-CT). For instance, Amber would use one identified Smartboard resource to help her students engage through the models of life cycles.

Hour of Code. Amber chose to experience the 6+ age programming course based on her teaching interest. She assumed her future students would be easily attracted by this coding activity embedded with the familiar Angry Bird characters. However, she became bored with the activities very quickly due to the repetitive concepts and length of the course. She suggested that the course could be designed to be shorter to avoid having players practice the same concept multiple times.

Lesson Plans (T1, T2, T3)

Scratch Lesson Plan (3.13/4). Amber planned a multiple-section lesson to incorporate programming (TK-CT) in a fourth-grade social studies class (TPACK-CT). Specifically, she first introduced the concept of programming using a CS Unplugged activity "Harold the Robot", followed by presenting the basics of Scratch and showing them a couple of Scratch stories. After then, students would work in small groups to create a Scratch story that represents historical events in chronological order.

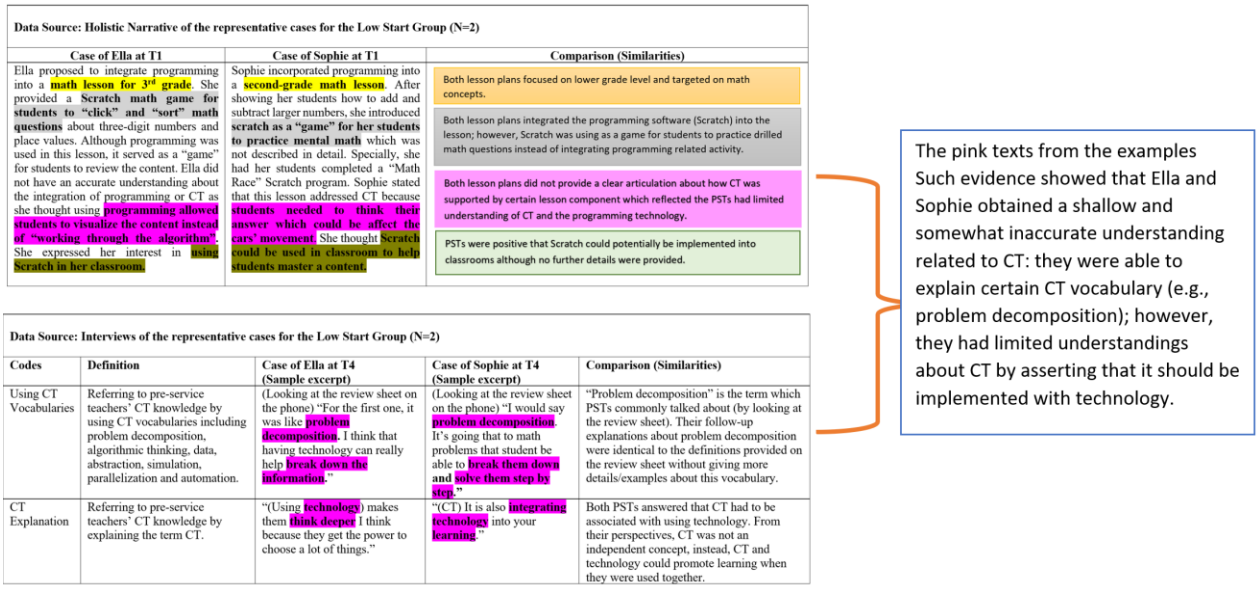
Concept Mapping Lesson (4/4). Amber planned to embed the concept mapping tool into her science unit. After students received instructions about the roles of water in the earth's system process, they would be assigned into groups to create a concept map (TPACK-CT) that represents the water cycle (TPACK-CT). Considering the age of her students (second grade) who might have difficulty in navigating the online concept mapping tool, Amber set several requirements (e.g., the model needs to contain high-level words) and provided an example using the tool.

Case Report (3.5/4). Amber modified and taught her science lesson about the water cycle integrated with the concept mapping tool (TK-CT) in her field placement. After her observation in her classroom, she found her students did not really use the Chromebook very often, so she assumed they might not be able to navigate the online concept mapping tool given the time of the lesson. Therefore, the concept mapping activity was changed from small group activities to a whole class activity. In this lesson, students were selected to come to the smartboard to drag and drop labels that fit the water cycle concept map created by the teacher (TPACK-CT). As Amber reflected, only 4 to 5 students had the chance to come to the smartboard and physically move the labels while the other students observed.

Overall
Amber was observed to be integrating CT into her science lesson that represents the life cycle or water cycle. Her programming lesson, concept mapping lesson and case report reflected that she obtained a moderate to high level of TPACK-CT since she recognized how to guide students learning to use a new tool before having them use it for completing a task for the lesson. Moreover, she understood how to modify the lesson due to the context constraint. She also expressed a high interest in integrating programming into her class.

Figure 3.6 Holistic Analysis Narrative of Amber (Part 1)

Stage III – Developing Profiles (Within-case analysis). I defined each trajectory as a profile. To thoroughly portray each profile, I combined data from the representative cases as well as the other pre-service teachers' lesson plans generated at the previous coding stages. The combination process involved a comparison between the representative cases and the other pre-service teachers' lesson plans. In particular, I first documented the coding patterns of the pre-service teachers' lesson plans then examined how well the representative cases aligned with these data. Finally, I distilled the commonalities among the data to portray each profile (Palak & Walls, 2009). These commonalities were described as characteristics of each profile which will be presented in Chapter 4. The development of trajectory profiles included three levels of comparison. The first comparison focused on comparing two representative cases within each group based on their holistic analysis narratives and interview data (Figure 3.7). The second comparison moved from individual comparison to whole group comparison. In particular, I summarized the codes and categories of the lesson plans at each time point within each trajectory (Figure 3.8). Level three focused on extracting the similarities between individual and whole group comparisons (Figure 3.9).



Data Source: Holistic Narrative of the representative cases for the Low Start Group (N=2)

Case of Ella at T1	Case of Sophie at T1	Comparison (Similarities)
Ella proposed to integrate programming into a **math lesson for 3rd grade**. She provided a **Scratch math game for students to "click" and "sort" math questions** about three-digit numbers and place values. Although programming was used in this lesson, it served as a "game" for students to review the content. Ella did not have an accurate understanding about the integration of programming or CT as she thought using **programming allowed students to visualize the content instead of "working through the algorithm"**. She expressed her interest in **using Scratch in her classroom**.	Sophie incorporated programming into a **second-grade math lesson**. After showing her students how to add and subtract larger numbers, she introduced **scratch as a "game" for her students to practice mental math** which was not described in detail. Specially, she had her students completed a "Math Race" Scratch program. Sophie stated that this lesson addressed CT because **students needed to think their answer which could be affect the cars' movement**. She thought **Scratch could be used in classroom to help students master a content**.	Both lesson plans focused on lower grade level and targeted on math concepts. Both lesson plans integrated the programming software (Scratch) into the lesson; however, Scratch was using as a game for students to practice drilled math questions instead of integrating programming related activity. Both lesson plans did not provide a clear articulation about how CT was supported by certain lesson component which reflected the PSTs had limited understanding of CT and the programming technology. PSTs were positive that Scratch could potentially be implemented into classrooms although no further details were provided.

Data Source: Interviews of the representative cases for the Low Start Group (N=2)

Codes	Definition	Case of Ella at T4 (Sample excerpt)	Case of Sophie at T4 (Sample excerpt)	Comparison (Similarities)
Using CT Vocabularies	Referring to pre-service teachers' CT knowledge by using CT vocabularies including problem decomposition, algorithmic thinking, data, abstraction, simulation, parallelization and automation.	(Looking at the review sheet on the phone) "For the first one, it was like **problem decomposition**. I think that having technology can really help **break down the information**."	(Looking at the review sheet on the phone) "I would say **problem decomposition**. It's going that to math problems that student be able to **break them down and solve them step by step**."	"Problem decomposition" is the term which PSTs commonly talked about (by looking at the review sheet). Their follow-up explanations about problem decomposition were identical to the definitions provided on the review sheet without giving more details/examples about this vocabulary.
CT Explanation	Referring to pre-service teachers' CT knowledge by explaining the term CT.	"(Using **technology**) makes them **think deeper** I think because they get the power to choose a lot of things."	"(CT) It is also **integrating technology** into your **learning**."	Both PSTs answered that CT had to be associated with using technology. From their perspectives, CT was not an independent concept, instead, CT and technology could promote learning when they were used together.

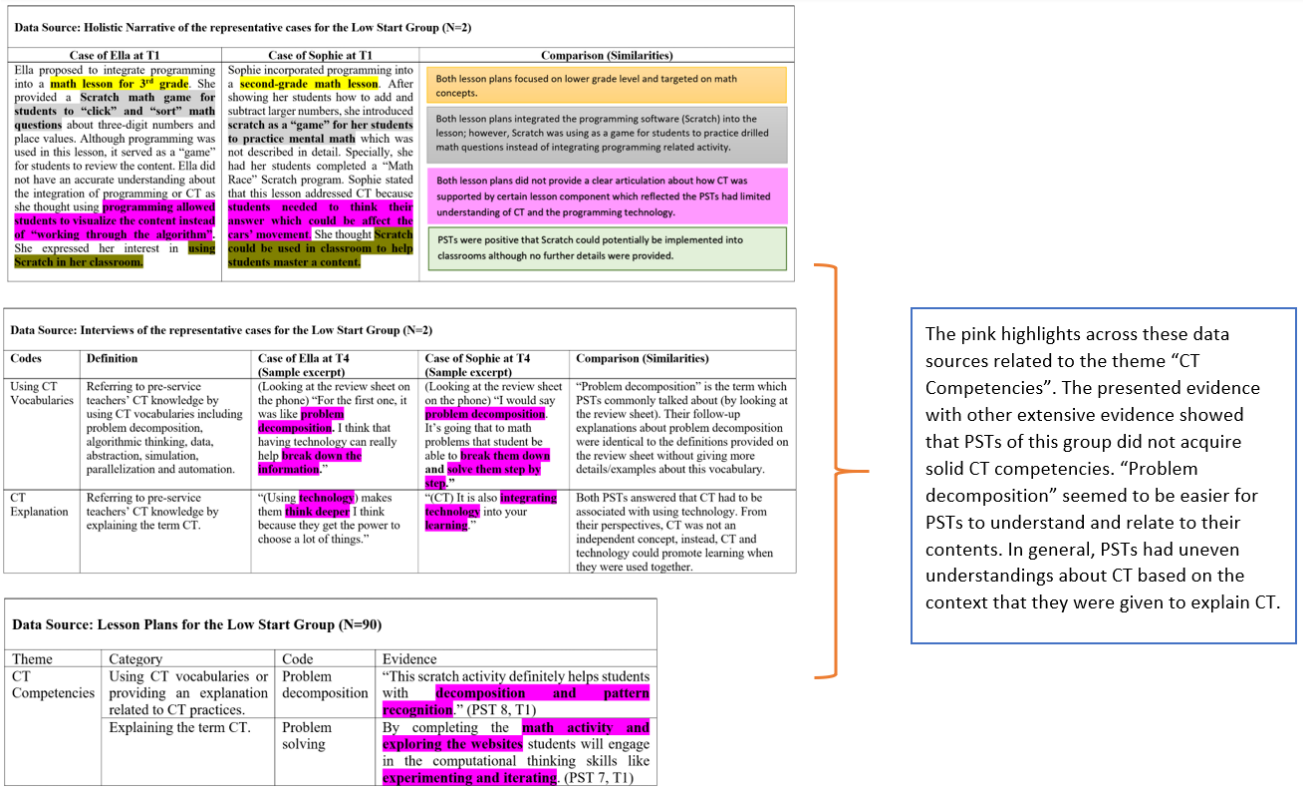
The pink texts from the examples Such evidence showed that Ella and Sophie obtained a shallow and somewhat inaccurate understanding related to CT: they were able to explain certain CT vocabulary (e.g., problem decomposition); however, they had limited understandings about CT by asserting that it should be implemented with technology.

Figure 3.7 Example of Across-case Comparison (Low Start Group)

Data Source: Lesson Plans for the Low Start Group (N=90)

Theme	Category	Code	Evidence
CT Competencies	Using CT vocabularies or providing an explanation related to CT practices.	Problem decomposition	"This scratch activity definitely helps students with **decomposition and pattern recognition**." (PST 8, T1)
	Explaining the term CT.	Problem solving	By completing the **math activity and exploring the websites** students will engage in the computational thinking skills like **experimenting and iterating**. (PST 7, T1)

Figure 3.8 Example of Within-profile Comparison (Low Start Group)



Data Source: Holistic Narrative of the representative cases for the Low Start Group (N=2)

Case of Ella at T1	Case of Sophie at T1	Comparison (Similarities)
Ella proposed to integrate programming into a **math lesson for 3rd grade**. She provided a **Scratch math game for students to "click" and "sort" math questions** about three-digit numbers and place values. Although programming was used in this lesson, it served as a "game" for students to review the content. Ella did not have an accurate understanding about the integration of programming or CT as she thought using **programming allowed students to visualize the content instead of "working through the algorithm"**. She expressed her interest in **using Scratch in her classroom**.	Sophie incorporated programming into a **second-grade math lesson**. After showing her students how to add and subtract larger numbers, she introduced **scratch as a "game" for her students to practice mental math** which was not described in detail. Specially, she had her students completed a "Math Race" Scratch program. Sophie stated that this lesson addressed CT because **students needed to think their answer which could be affect the cars' movement**. She thought **Scratch could be used in classroom to help students master a content**.	Both lesson plans focused on lower grade level and targeted on math concepts. Both lesson plans integrated the programming software (Scratch) into the lesson; however, Scratch was using as a game for students to practice drilled math questions instead of integrating programming related activity. Both lesson plans did not provide a clear articulation about how CT was supported by certain lesson component which reflected the PSTs had limited understanding of CT and the programming technology. PSTs were positive that Scratch could potentially be implemented into classrooms although no further details were provided.

Data Source: Interviews of the representative cases for the Low Start Group (N=2)

Codes	Definition	Case of Ella at T4 (Sample excerpt)	Case of Sophie at T4 (Sample excerpt)	Comparison (Similarities)
Using CT Vocabularies	Referring to pre-service teachers' CT knowledge by using CT vocabularies including problem decomposition, algorithmic thinking, data, abstraction, simulation, parallelization and automation.	(Looking at the review sheet on the phone) "For the first one, it was like **problem decomposition.** I think that having technology can really help **break down the information**."	(Looking at the review sheet on the phone) "I would say **problem decomposition**. It's going that to math problems that student be able to **break them down and solve them step by step**."	"Problem decomposition" is the term which PSTs commonly talked about (by looking at the review sheet). Their follow-up explanations about problem decomposition were identical to the definitions provided on the review sheet without giving more details/examples about this vocabulary.
CT Explanation	Referring to pre-service teachers' CT knowledge by explaining the term CT.	"(Using **technology**) makes them **think deeper** I think because they get the power to choose a lot of things."	"(CT) It is also **integrating technology** into your **learning**."	Both PSTs answered that CT had to be associated with using technology. From their perspectives, CT was not an independent concept, instead, CT and technology could promote learning when they were used together.

Data Source: Lesson Plans for the Low Start Group (N=90)

Theme	Category	Code	Evidence
CT Competencies	Using CT vocabularies or providing an explanation related to CT practices.	Problem decomposition	"This scratch activity definitely helps students with **decomposition and pattern recognition**." (PST 8, T1)
	Explaining the term CT.	Problem solving	By completing the **math activity and exploring the websites** students will engage in the computational thinking skills like **experimenting and iterating**. (PST 7, T1)

The pink highlights across these data sources related to the theme "CT Competencies". The presented evidence with other extensive evidence showed that PSTs of this group did not acquire solid CT competencies. "Problem decomposition" seemed to be easier for PSTs to understand and relate to their contents. In general, PSTs had uneven understandings about CT based on the context that they were given to explain CT.

Figure 3.9 Example of Developing Profile (Low Start Group)

Stage IV – Comparing Profiles (Across-case analysis). My comparisons across three trajectory profiles were based on the characteristics generated from the previous coding stage. In particular, I created joint displays which connected the quantitative and qualitative data strands based on six representative cases to perform the comparison (Borg, 2011; Creswell & Plano-Clark, 2017). This coding stage aimed to address the "generalizability" of each unique trajectory (Ayres, Kavanaugh, & Knalf, 2003; Sandelowski, 1996). An extensive discussion related to comparing these profiles will be provided in Chapter 5.

Chapter 4

RESULTS

Phase I Study

In this chapter, I report the study findings arranged by the two phases of the study. Phase I section presents quantitative results on the research question "How does participation in a redesigned educational technology course influence pre-service teachers' understanding of CT as illustrated in pre and post survey data?" Subsequently, I report qualitative findings related to the research question "How do pre-service teachers perceive the implementation of CT into K-8 core content areas, including the role of technology during CT implementation?" Finally, I provide integrated results from the quantitative and qualitative data using a joint display to answer the third research question "To what extent do pre-service teachers' perceptions of CT implementation as illustrated in the qualitative results relate to their CT understanding as illustrated in the quantitative survey results?"

Participants' Knowledge and Attitudes related to CT (Quantitative Result). On average, participants showed significantly higher scores on the post-survey than on the pre-survey ($t = 5.19$, $df = 134$, $p = .000$). The effect size was moderate (Cohen, 1988, $d = 0.45$) and represents a moderate difference between the two time periods. Table 4.1 demonstrates significant gains ($p < 0.05$) for three CT constructs: Definition, classroom

use and knowledge and belief in using computer tools in future classrooms. No significant gains were found in participants' comfort and interest towards CT, and perceived importance for future career goals. A large effect size (d > 0.5) was documented for CT definition and knowledge and belief while a medium effect size (d = 0.36) was documented for classroom use. These findings indicate that pre-service teachers benefitted positively from the course, particularly in enhancing their understanding of specific CT constructs.

Table 4.1 CT Knowledge and Attitude Pre/ Post-Dependent (paired) t-test Statistical Analysis.

Constructs	**Number of Items**	**Mean Difference**	**Standard Deviation**	***t***	***df***	***p* Significance *(Two-Tailed)***	**Effect Size (d)**
Definition	4	0.25	0.42	7.03	134	.000**	0.74
Comfort	6	0.08	0.39	2.44	134	0.016	0.22
Interest	4	0.05	0.54	1.19	134	0.238	0.1
Classroom	2	0.16	0.54	3.34	134	.001**	0.36
Career	5	-0.01	0.5	-0.38	134	0.704	-0.04
Knowledge and Belief	5	0.28	0.46	6.92	134	.000**	0.63
Total	26	0.13	0.29	5.19	134	.000**	0.45

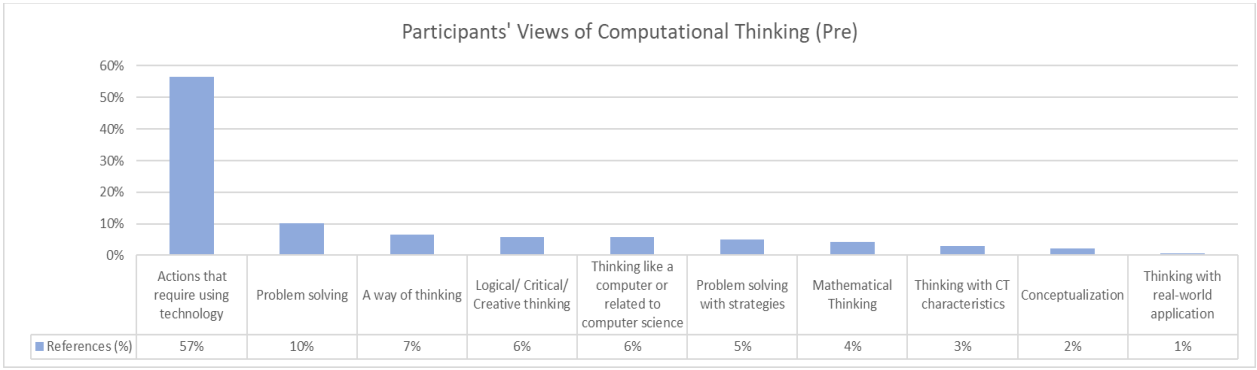
Participants' Conception Related to CT Implementation (Qualitative Result).

A total of 810 responses from the pre- and post-questionnaire were collected from 135 participants. Findings from three open-ended questions noted improvements in participants' understanding of CT related concepts, CT implementation, and the role of technology in CT implementation before and after their participation in the redesigned educational technology course.

Participants' Views of Computational Thinking. Ten categories presented in Figure 4.1 below were generated from a total of 138 codes from participants' pre-responses to the question "What do you think the term Computational Thinking means?" Without having prior knowledge of CT, the majority of the participants provided guesses and assertions about CT definitions in their responses. As participants defined CT concepts, 57% of the codes were categorized as "CT was actions (teaching, learning, thinking) that related to using technology". For instance, one respondent believed that CT "has to do with thinking that involves technology". Moreover, participants thought that CT meant thinking like computers (6% of the references). Nevertheless, 7% of the coding references indicated that a few participants were able to recognize CT as a problem-solving methodology.

Ten categories presented in Figure 4.1 were identified from 146 codes from all participants' post-responses to the same question. In contrast to the pre-survey responses, viewing CT as a "problem-solving process" was largely reported by the participants in their post-responses (36% of the references). Moreover, 12% of the codes revealed that an increasing number of participants were able to articulate CT by focusing on key practices such as abstraction, algorithms and so forth. For example, one participant reported that CT "is about thinking abstractly and recognizing patterns to think logically and problem solve". However, a few responses were coded as limited understandings since the participants were unable to provide a clear statement about the concept but instead viewed CT as "skills to use a computer" or "think like a computer".

Compared with their pre-questionnaire responses, participants demonstrated developing CT understandings as illustrated in their post-questionnaire. The biggest difference between participants' pre- and post-view of CT concepts was reflected by their detailed descriptions of CT such as using CT specific vocabulary (e.g., abstractions and data).



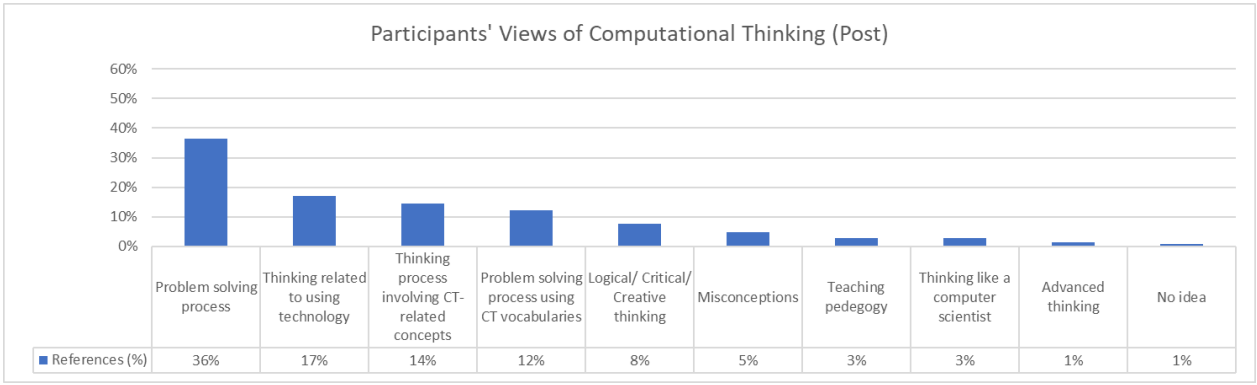


Figure 4.1 Participants' Pre- (Top) and Post- (Bottom)Viewpoints of CT.

Computational Thinking Implementation in K-8 Classrooms. All participants responded "yes" to the question "Do you think Computational Thinking can be integrated into the classroom? If yes, how would you implement Computational Thinking into your future classroom? If no, why do you think Computational Thinking cannot be integrated

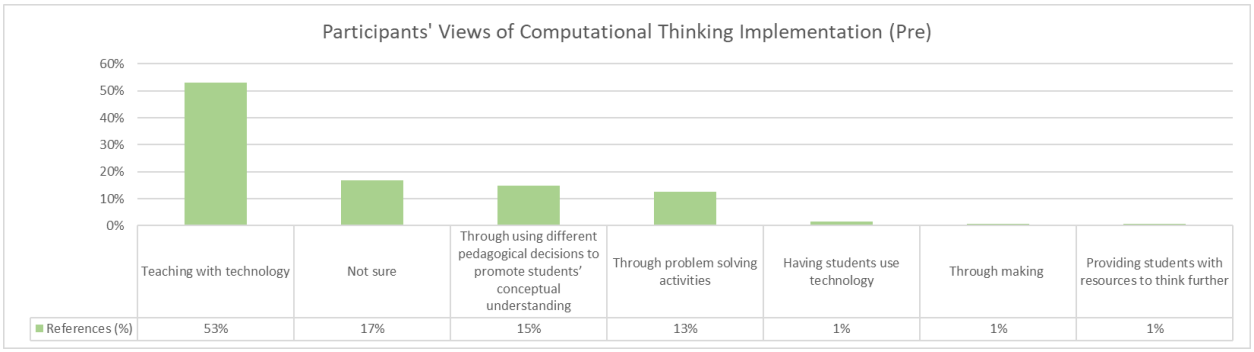
into the classroom?" and provided the following explanations about CT implementation in their pre- and post-questionnaire.

Seven categories presented in Figure 4.2 were originated from a total of 136 codes from all participants' pre-responses to the question. According to Figure 4.2, 53% of the coding references indicated that participants misunderstood the concept of CT and noted that it could be automatically implemented in classroom settings merely through the use of technology. However, some participants indicated employing various pedagogical strategies to implement CT into the classroom, such as "helping students connect with prior knowledge". Moreover, 13% of the codes indicated that some participants considered using problem-solving activities for implementing CT in the classroom.

Ten categories presented in Figure 4.2 below emerged from a total of 155 codes from participants' responses to the same question in the post-questionnaire. Figure 4.2 indicates that the participants demonstrated an improved understanding of integrating CT into the classroom. About 32% of the coding references indicated that CT could be embedded with other disciplines such as math, science, literacy and social studies. Moreover, these respondents illustrated how implementation would occur through examples with using specific computing tools and pedagogy within a certain content: "One example of a way I would integrate computational thinking is by doing the electronic snap circuits in a science lesson. I think this would be fun for the children, but it will also get them to exercise their computational thinking skills of sequencing, codes, and patterns. This will help them think about exactly what they need to do to make the circuit complete." Moreover, participants indicated that using computing tools could be a

valuable way to facilitate CT implementation into general education, including using the concept mapping tool: “Concept mapping. For something as simple as beginning, middle and end of a book or for informational texts for similarities or differences, concept mapping is a way to organize thoughts and elaborate on those ideas you have.” Additionally, participants identified different pedagogies that could be used to promote students’ CT, including problem-solving, seeing patterns, analyzing data and so forth. Finally, using non-computing technology, such as board games, was brought up by some participants as they envisioned CT implementation in their classrooms.

These findings indicated that participants began to gain deeper understandings as they described possible ways to implement CT into their future classrooms. Specifically, an increasing population started to recognize that CT implementation should go beyond viewing CT as a stand-alone concept; thereby, they integrated CT with content, pedagogy and technology, to foster students’ developing understanding in both disciplinary knowledge and CT.



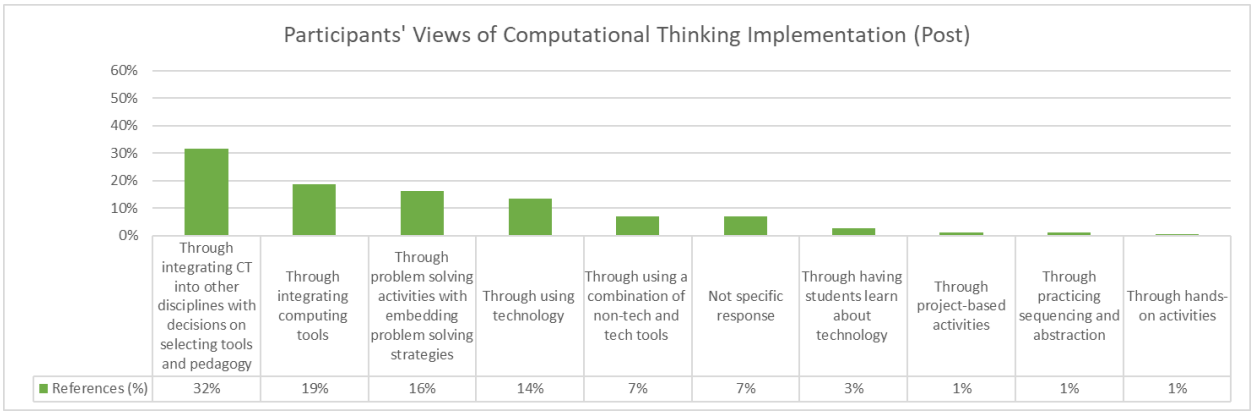


Figure 4.2 Participants' Pre- (Top) and Post- (Bottom) Viewpoints of CT Implementation.

Use of Technology through CT Integration. Six categories presented in Figure 4.3 below were derived from a total of 138 codes from all participants' pre-responses to the question "How can technologies be used to help develop school students' Computational Thinking skills?" Since most of the participants did not obtain an accurate understanding of CT before they attended this redesigned educational technology course, they were unable to conceptualize the role of technology in promoting students' CT skills: 34% of the coding references were categorized as "Not sure." Additionally, 30% of the codes acknowledged that technology has the potential to provide resources for students to conduct research (21%) or to practice CT skillsets (9%). However, 35% of codes indicated that participants thought technology alone could provide students with

resources (18%) and promote students' CT skills (17%), regardless of instruction, curriculum, and other factors.

Seven categories presented in Figure 4.3 below emerged from a total of 137 codes based on participants' responses to the same question in the post-questionnaire. In their post-survey responses, participants were more specific in elaborating practices in which technology could be used to develop students' CT skills. Having coding activities (23% of the coding references), having students create computing artifacts (10% of the coding references), using technological applications related to conducting research projects (17% of the coding references), or using computing tools (12% of the coding references) were commonly mentioned by participants as pedagogical strategies for implementing CT through the use technology.

Noticeably, there was still a certain number of participants who exhibited a limited understanding about the role of technology in promoting students' CT skills. These limited understandings often started with phrases such as "technology allows …", "technology gets them to think about …" or "technologies can develop/help …" Such responses revealed that these participants had a limited understanding of the role of technology as it is used to enhance CT implementation. More importantly, these participants were unable to connect content and pedagogical knowledge with technology to help promote students' CT skills.

These data indicate that participants demonstrated understandings in specifying how to use technology in the classroom to facilitate students' development in CT skills.

However, some participants continued to exhibit limited understanding even after completing the course.

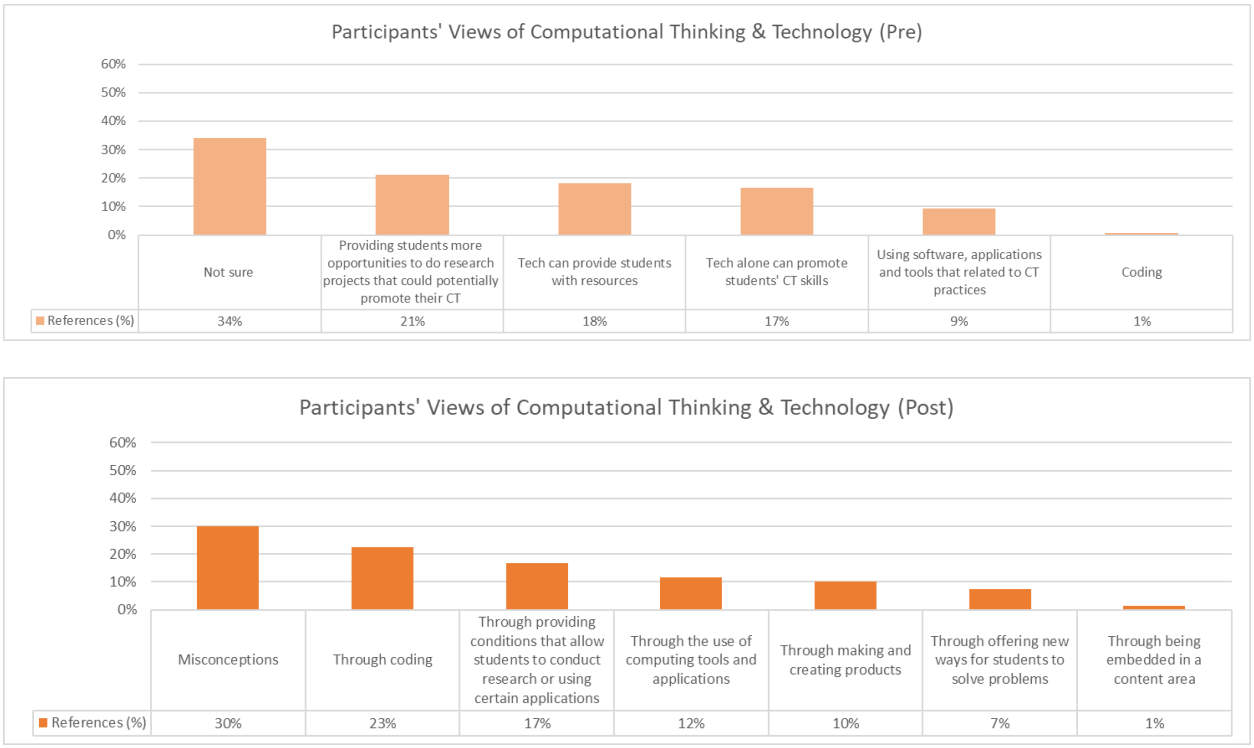


Figure 4.3 Participants' Pre- (Top) and Post- (Bottom)Viewpoints of CT and Technology.

Integrated Results. Figure 4.4 below presents the integrated results based on the quantitative and qualitative findings shown above. In Figure 4.4, qualitative results for each open-ended question are presented as themes instead of categories. Major themes for each analysis were distilled based on the categories shown in Figures 4.4. Due to the limitations of only having three open-ended questions in the instrument, these questions could only be matched to certain survey items associated with specific CT constructs. Hence, for quantitative results, three CT constructs which are Definitions, Classroom and Knowledge and belief are presented in Figure 4.4. Noticeably, participants achieved a

significant gain in all three constructs. The other CT constructs, such as comfort, interest and career, are not included in the integrated results section because the open-ended questions were not designed to correspond to all CT constructs listed in the survey.

Integrated results shown in Figure 4.4 reflected that participants' understanding of CT concepts were significantly improved after their participation in this redesigned educational technology course. For instance, they were able to interpret CT concepts through detailed and more accurate explanations in their post-responses: 36% of coding references illuminated that participants considered CT as problem-solving. Additionally, 29% of the coding references revealed an advanced explanation of embedded CT characters into the problem-solving process.

More importantly, participants were able to pinpoint how CT could be implemented through using computing tools within a content area, which significantly distinguished and expanded from their prior understanding of CT implementation. Accordingly, participants demonstrated a significant gain in the classroom CT construct.

Finally, although participants demonstrated significant gains in the knowledge and belief construct, their post-responses to the corresponding open-ended question did not fully align with the quantitative results. In fact, participants' open-ended responses revealed that some participants still held limited understandings about the role of technology in promoting students' CT skills. Although a large proportion of codes signaled that participants recognized the potential effects of integrating technology to facilitate students' CT development, these responses which only mentioned the tools or

functions of technology, did not fully demonstrate participants' understanding of how the technology could be used to promote CT development.

Qualitative Results			**Quantitative Results**	**Mixed-Method Integrated Results**
Open-Ended Questions	Pre-Response (Theme, %)	Post-Response (Theme, %)	Significant CT Construct (Mean Difference, p-value)	
CT Concepts	CT means problem-solving in general. (10%)	CT means problem-solving in general. (36%)	CT Definition (.25, .000**)	***Confirmation*** Participants demonstrated more accurate understandings of CT by recognizing CT as a problem-solving process, as well as noticing CT characteristics in their post-responses. This indicated that they had reached a significant gain in CT understandings.
	CT is a problem-solving process that involves a series of characters, including analyzing data, abstraction and so forth. (8%)	CT is a problem-solving process that involves a series of characters, including analyzing data, abstraction and so forth. (29%)		
	CT means to think logically or critically about solving problems. (6%)	CT means to think logically or critically about solving problems. (8%)		
CT Implementation	Implementing CT through teaching and learning using technology. (54%)	Implementing CT through a context of content, pedagogy and computing tools. (50%)	Classroom (.16, .001**)	***Confirmation*** Participants demonstrated an increased understanding about CT implementation in their post-responses to the open-ended question, as well as in their post-survey responses. ***Expansion***
	Implementing CT by providing students with learning opportunities to conceptualize concepts. (28%)	Implementing CT with the teaching and learning assisted by non-specific non-tech and tech tools. (23%)		

		Implementing CT through a series of design activities that promote problem solving and research. (19%)		Participants provided explicit examples in their post-responses about how to implement CT into their classroom, especially integrating CT into the context of content, pedagogy and technology. Evidence revealed that participants were able to consider the factors involved in CT implementation; however, these factors were not captured by the survey items.
CT & Technology	Technology alone can promote students' CT. (35%)	Technology alone can promote students' CT. (30%)	Knowledge and Belief (.25, .000**)	***Confirmation*** Participants provided more in-depth and reasonable explanations in their post-responses about how technology could be integrated to promote students' CT skills. ***Discordance*** Participants' prior views of CT and technology mainly belonged to limited understandings about the use of technology in CT integration;
	Not sure how technology could be integrated to promote students' CT. (34%)	Technology offers new options for students to gather information and ways to solve problems. (24%)		
	Technology provides students with new options to access information and resources. (30%)	Technology could be used to promote CT through coding activities. (23%)		

		Computing tools allow students to develop CT through problem-solving and making products. (22%)		however, their post-responses indicated that they were able to envision using technology to promote students' thinking through more specific viewpoints, such as using technology to provide CT related activities that would potentially affect students' CT development. However, these slightly improved responses did not correspond to how computing tools could be embedded in the lessons through design.

Figure 4.4 A Joint Display of Integrated Results from Qualitative and Quantitative Strands.

Phase II Study

The phase II section first presents the quantitative results to the research question "What trajectory of TPACK-CT do preservice teachers exhibit during their participation in the redesigned educational technology course?". Based on the quantitative data which shows three TPACK-CT trajectories, I further provide evidence from the quantitative and qualitative data to illustrate how TPACK-CT was represented in each trajectory. The synthesized findings are presented to answer the research questions "How is TPACK-CT represented in pre-service teachers' course-related CT products?" and "What are the similarities and differences across the different TPACK-CT trajectories?"

Defining TPACK-CT trajectories. Results from the one-way repeated measures ANOVA determined that means of all participants' overall TPACK-CT scores significantly differed between time points ($F(2, 112) = 40.27$, $p < 0.0005$). Post hoc tests using the Bonferroni correction revealed that participants' overall TPACK-CT scores significantly increased in the concept mapping lessons (T2) and final case narratives (T3) compared with the Scratch programming design (T1). However, there was a slight reduction, 0.58 point, in participants' TPACK-CT scores from their concept mapping lessons to the final case narrative, which was statistically significant ($p < 0.0005$). Figure 4.5 presents the boxplots of TPACK-CT scores among all participants at three tasks. It is worth noting that the scores present in Figure 4.5 represent pre-service teachers' overall TPACK-CT scores and do not attempt to represent particular CT concepts (e.g., algorithmic thinking) reflected by each pre-service teachers' lesson plans.

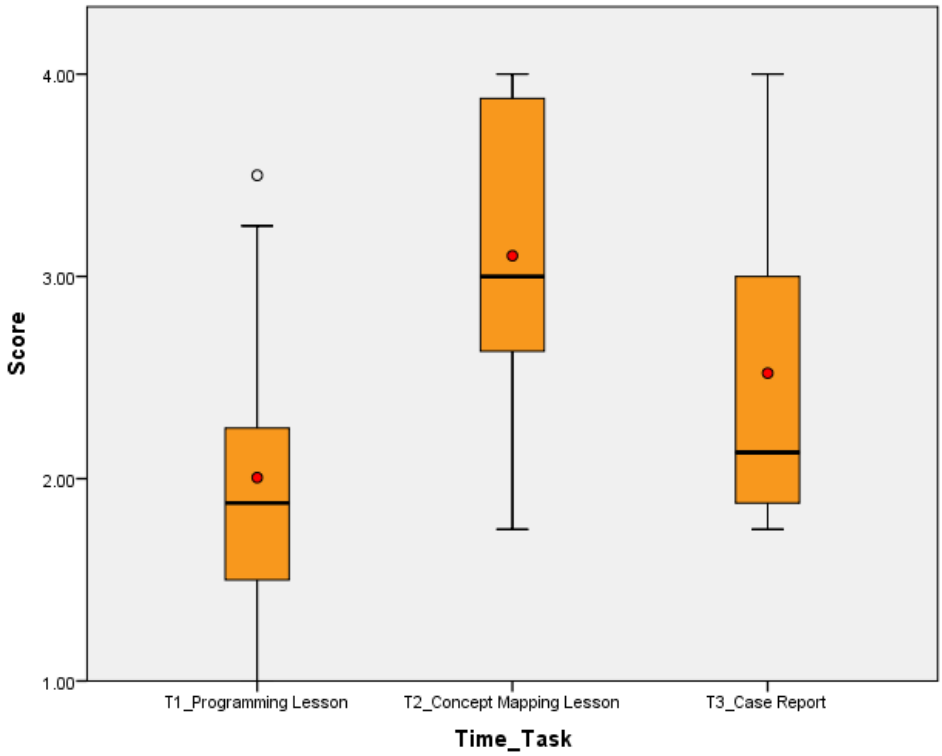


Figure 4.5 Boxplots of TPACK-CT Scores among All Participants at Different Tasks (N=57).

Three TPACK-CT trajectories were generated after the pre-service teachers were assigned into three groups based on their initial lesson plan scores (T1). Table 4.2 presents the means and standard deviations for the three groups on the lesson plan scores separated by time. Results from the repeated measures ANOVA revealed that the group-by-time interaction was significant (Wilks' $\lambda = .561$, $F = 8.88$, *df* [2, 4], $p = .001$). The obtained effect for group-by-time interaction presented a large effect size (eta squared = .251). Figure 4.6 below presents the TPACK-CT scores of three trajectory groups at different tasks. As shown in Figure 4.6, 70% of the pre-service teachers of the Low Start Group received a same TPACK-CT score (1.5 out of 4.0) which resulted to its respective boxplot to have the same first, second and third quantiles. .

Table 4.2 Mean and Standard Deviations by Groups and Times.

Time_Task	Group	M	SD
T1_Programming Lesson Plan	Low Start	1.53	0.17
	Medium Start	2.23	0.19
	High Start	3.15	0.17
T2_Concept Mapping Lesson Plan	Low Start	3.03	0.61
	Medium Start	2.98	0.84
	High Start	3.58	0.47
T3_Case Report	Low Start	2.51	0.75
	Medium Start	2.53	0.87
	High Start	2.53	0.82

Note: *M* = mean, *SD* = standard deviation.

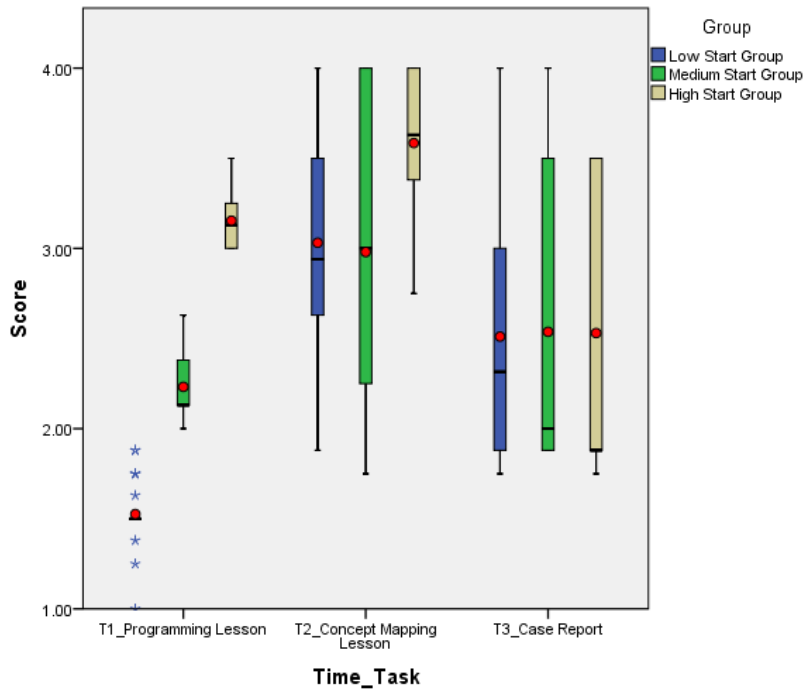


Figure 4.6 Boxplots of TPACK-CT Scores of Three Trajectory Groups at Different Tasks.

Tukey post hoc tests from three one-way ANOVA tests showed that a statistically significant difference existed among "Low Start", "Medium Start" and "High Start" groups at T1 ($F = 318.14$, *df* [2, 56], $p = .001$); however, no significant difference existed among these groups in the concept mapping lessons (T2) and the case reports (T3), although they started with significant difference in the programming lessons (T1).

Overall, results indicated that non-linear TPACK-CT developments existed among participants. Despite starting with distinct TPACK-CT scores initially (T1), all groups continued to obtain higher mean scores of TPACK-CT in designing the hypothetical concept mapping lessons (T2). However, the pre-service teachers' TPACK-CT scores, on average, appeared to be lower as they implemented their CT-infused lessons in authentic settings (T3). Results from the quantitative analysis defined three TPACK-CT trajectories among the participants. These trajectories tended to have higher mean scores of the TPACK-CT at T2 and T3, although they obtained different starting points. The following section provides detailed analysis about how TPACK-CT was presented among these groups based on extensive qualitative analyses.

TPACK-CT representation of the Low Start Group. In this section, I provide an overview of the Low Start Group TPACK-CT trajectory. I first present the TPACK-CT trajectory for this group, and subsequently illustrate the representation of CT competencies, attitude and knowledge related to computing technologies reflected by this group. Finally, I describe the contextual factors that influenced pre-service teachers' implementation of CT in classroom settings.

Technological, pedagogical and content representations in CT implementation (TPACK-CT). Results of the one-way repeated measures ANOVA determined that means of participants' overall TPACK-CT scores of the Low Start Group significantly differed between time points ($F(2, 58) = 58.85$, $P < 0.0005$). Post hoc tests using the Bonferroni correction revealed that participants' mean scores of TPACK-CT of the Low Start Group were significantly higher in the concept mapping lessons (T2) and final case narratives (T3) compared with the Scratch programming design (T1). However, there was a slight reduction, 0.52 point, in participants' mean score of TPACK-CT from their concept mapping lessons to the final case narrative, but it was not statistically significant ($p = .0.009$). Figure 4.7 below provides the boxplots of TPACK-CT scores among participants of the Low Start Group at three different tasks.

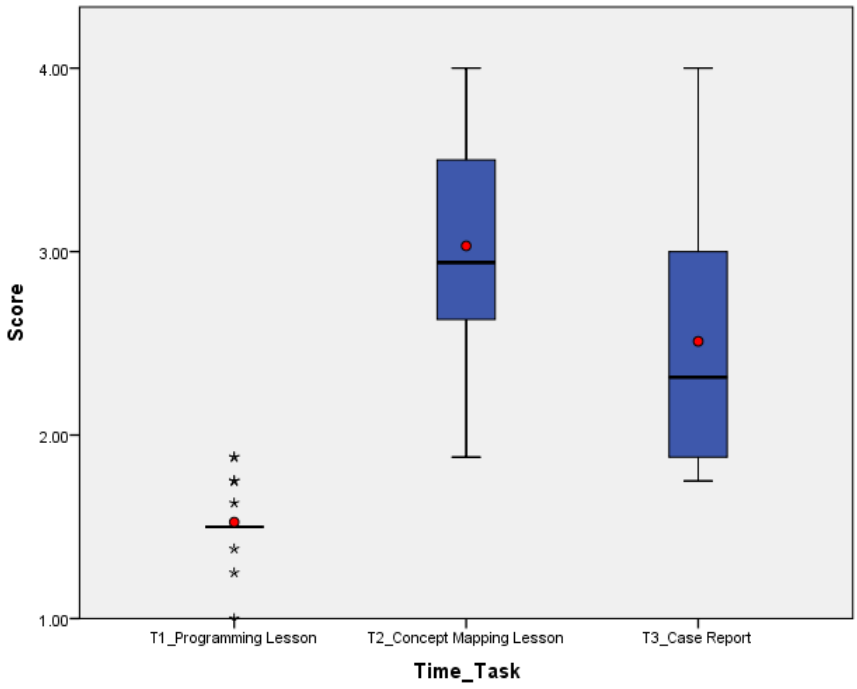


Figure 4.7 Boxplots of TPACK-CT Scores at Different Tasks for the Low Start Group (N=30).

As shown in the quantitative results, the pre-service teachers from the Low Start Group started with a low TPACK-CT score at T1. The mean score of TPACK-CT became higher at T2 and T3, although the mean slightly decreased at T3. Table 4.3 below presents a summary about the grade levels and content areas addressed among the three lesson plans. As shown in Figure 4.8 below which presents a summary about CT practices extracted by the author, only a few lesson plans could be identified to echo certain CT practice (e.g., simulation), although these activities were described briefly. For instance, one brief lesson plan was found to be related to the CT practice of simulation: "I will have students use the Fox Survival program and have them code their fox to survive the bear attack—this will not only help them further their computational thinking, but also see how a smaller animal can survive a predator" (PST 52, T1). However, such lessons still received low TPACK-CT scores since they did not provide further justification to instantiate the pre-service teachers' pedagogical, content and technological decisions related to the creation of a CT-infused lesson. Figure 4.8 reflects that pre-service teachers' lessons designed at T2 addressed a variety of CT practices compared to the lessons designed at T1 and T3. For lessons designed at T2, most pre-service teachers used concept mapping tools to promote students' content knowledge and CT understanding on data. At T3, some pre-service teachers were able to utilize computing technology into the design and implementation of a CT lesson, such as creating an interactive Smartboard activity for students to sort items related to "wants" and "needs" in a social study lesson (TPACK-CT). However, some lessons which used

the Smartboard did not address CT at all (e.g., using the Smartboard for the teacher to record students' responses to comprehension questions in a reading class).

Table 4.3 Overview of the Lesson Design Products of the Low Start Group.

	T1_Programming Lesson Plan	**T2_Concept Mapping Lesson Plan**	**T3_Case Report**
Content Area			
Math	63%	6%	17%
Science	13%	30%	23%
Social Studies	13%	30%	40%
Literacy	10%	33%	17%
Programming	-	-	3%
Grade Level			
K -2nd Grade	47%	27%	37%
3rd -5th Grade	50%	60%	63%
6th -8th Grade	3%	13%	-

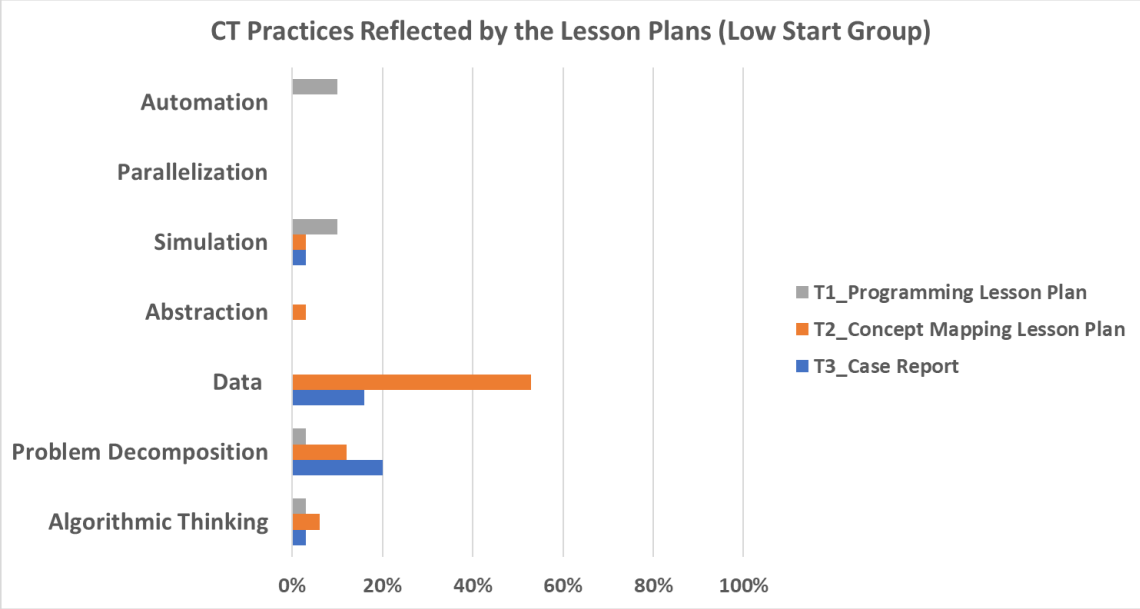


Figure 4.8 CT Practices Reflected by the Lesson Plans (Low Start Group)

CT competencies (CT). Pre-service teachers' CT-infused lesson plans reflected that they held basic and limited understandings of CT at first. Pre-service teachers in the Low Start group were asked to design a programming lesson which could be implemented in their classroom settings. Their lesson plans, however, did not specify how programming was used to support students' CT. According to Table 4.4 below, 53% of the pre-service teachers did not mention nor justify the term CT in their lessons. However, a growing number of pre-service teachers addressed CT in their concept mapping lessons by either using CT vocabularies or providing explanations related to CT concepts: "[With creating a concept map it] is important for students to be able to sequence their math for this lesson of order of operations, and so concept mapping promotes this, as they will work on sequencing their thoughts within the map. Students will have to use their previous pedagogical knowledge and critical thinking skills in order to figure out which words to put together, which will help them to achieve the overall goal" (PST 42, T2). This improvement of self-identifying specific CT practices did not continue in their T3 lesson plans, although some of the lessons were aligned with CT practices (Table 4.4). In fact, about half of the pre-service teachers defined CT as a general problem-solving process while the other half did not address CT in their case reports.

Table 4.4 CT Competencies of the Low Start Group.

CT Competencies (Low Start Group)	**T1_Programming Lesson Plan**	**T2_Concept Mapping Lesson Plan**	**T3_Case Report**
Using CT vocabularies or providing an explanation related to CT concepts	3%	53%	-
Viewing CT as Problem Solving Skills	43%	-	53%
Not Mentioned/ Not Related/ Unclear	53%	47%	47%

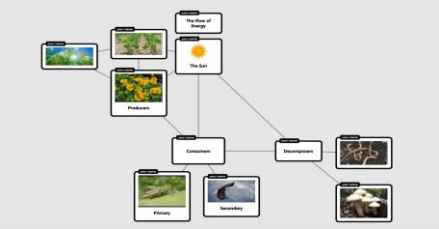
Attitudes and knowledge related to computing technologies (TK-CT). None of the pre-service teachers from the Low Start group had previously interacted with computing tools like Scratch. The majority of the pre-service teachers (53%) enjoyed programming in Scratch and were positive about using Scratch in their future classroom teaching. About 13% of the pre-service teachers reported that they were still exploring programming and were uncertain about whether they would implement programming in the future. About 30 % of the pre-service teachers reported that they were struggling with learning programming. Although these pre-service teachers did not fully enjoy their learning experience with Scratch, they recognized the importance and potential of embedding programming into instruction:

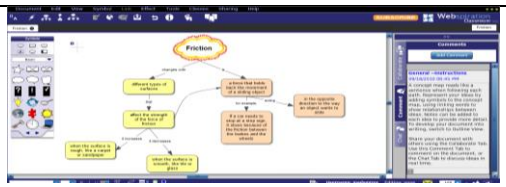
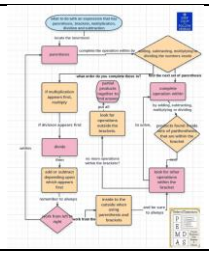
> "My experience with Scratch was not the best. Honestly, I found it very complicated and difficult to use. I understand how it could be useful to practice computational thinking, but I don't know if this is the best site to use. Unless the teacher can only have students using the basic skills, I feel that students will get frustrated and discouraged with this site. I see the benefits of using this site because computational thinking and programming is a very important skill

> students should practice more than they do. I personally liked the site we explored in the Hour of Code module better than this, but I do see that this could be utilized more as it can be integrated into many different lessons rather than just a game." (PST 29, T1)

Although most pre-service teachers of the Low Start Group reported being positively engaged in learning Scratch, their programming lesson plans reflected that they did not comprehend the Scratch functionalities thoroughly. In particular, their lessons did not address the programming features of Scratch (T1). Over 70% of the pre-service teachers used Scratch as a game for students to practice content-related concepts (e.g., multiplications) or as a visual aid for students to visualize contents (e.g., presenting the experiment about chemical reactions). Nevertheless, pre-service teachers became more comfortable and acquainted with navigating and integrating the concept mapping tools (T2). About 83% of the pre-service teachers provided self-created concept map products (Table 4.5) which were provided as examples for students to get familiar with using the tools (T2).

Table 4.5 Concept Mapping Examples of the Low Start Group.

PST ID	**Subject Area**	**Concept Map Example (73% of the PSTs of the Low Start Group created a concept map for their lesson).**	**Supported CT Concept (Defined based on the Learning Goals and Lesson Activities)**
11	Science		Simulation

29	Literacy		Decomposition
42	Math		Algorithmic Thinking

Noticeably, pre-service teachers of the Low Start Group demonstrated uneven understandings related to computing technologies in their final case reports. This was reflected by their selection of technologies in their CT lesson implementation. According to Table 4.6, 37% of the pre-service teachers were able to use Smartboard in their classroom, but the majority used Smartboard to display content related materials such as PowerPoint and videos. The pre-service teachers who implemented CT lessons were able to identify and integrate computing tools such as the programming tool: "the specific learning goal for the activity was for students to develop computational thinking skills through the process of trial and error while using an Hour of Code activity of their choice" (PST 16, T3). Their selected tools were found to be the ones that were introduced in the redesigned educational technology course. However, a number of the pre-service teachers selected technologies which couldn't be categorized as computing technologies, such as using visual presenters (e.g., Elmo). For example, one pre-service teacher asserted that: "our learning goal for technology is that students would use Plickers to display their mathematical knowledge" (PST 12, T3), however, this pre-service teacher

did not further explain how using Plickers related to promoting CT in this lesson. Additionally, many of the pre-service teachers chose to integrate the whiteboard (e.g., Smartboard) which could potentially promote CT; however, their lessons did not achieve such a purpose: "… we instead decided to print out the story problem and project it on the Smartboard during the lesson's launch phase" (PST 27, T3). In this case, this pre-service teacher used Smartboard as a visual representation tool instead of using it for designing CT-related activities. In the pre-service teachers' final case reports, about 80% of them had access to computing technologies in their lessons. However, only 40% of the lessons were aligned with CT implementation. This analysis suggests that the pre-service teachers did not acquire a solid background in bridging CT and technologies to achieve meaningful CT implementation.

Table 4.6 Selected Technologies for Final Case Reports of the Low Start Group.

Technology	**T3_ Case Report**
Interactive Whiteboard	37%
Plickers	13%
Kahoot	17%
Internet for Research	17%
Concept Map	6%
Hour of Code	3%
Elmo Projector	3%

CT implementation with contextual factors (TPACK-CT & Context). When pre-service teachers designed hypothetical lessons in T1 and T2, they focused more on the design of the lesson activities and were less concerned about the learning context. In contrast, the context factors became more salient in pre-service teachers' final case report (T3). In fact, the contextual factors often influenced how pre-service teachers planned,

implemented and reflected their technology-integrated lessons: pre-service teachers often considered several context factors while they designed the CT-infused lesson, including learners' content and technology background, and available technology in the classroom. For instance, one pre-service teacher was struggling to design a CT-infused lesson with technology due to having limited technology in her school: "Our school has little to no technology in the classrooms so it was difficult for us to think about how we could integrate technology into a lesson" (PST 15, T3). Additionally, the context factors influenced pre-service teachers' lesson implementation, such as students' behaviors related to using technology and technological issues during the lessons. For instance, one pre-service teacher reported a technological issue during the lesson when students were learning about the Great Depression with the Smartboard: "During this lesson, one challenge we faced was figuring out how to drag items in the Smartboard notebook. We had little experience working with the Smartboard application, so it was difficult for us to figure out how to maneuver it" (PST 17, T3). Although pre-service teachers were required to teach a CT-infused lesson with technology integration, a large portion of the lessons still neglected infusing CT by using technology to support different instructional and learning goals (Table 4.7).

Table 4.7 Purposes of Integrating Technologies for Final Cases of the Low Start Group.

Using Technology for	**T3_ Case Report**
Supporting CT and Content Understandings	40%
Representing Instructional Materials	27%
Assessing Learners' Knowledge	30%

Low Start Group Representative Cases. This section describes two representative cases of the Low Start TPACK-CT trajectory group. After a brief overview of each case, I focus on presenting results in four areas: representation of CT competencies, attitude and knowledge related to computing technologies, and contextual factors related to the implementation of CT in classroom settings.

Ella's case. Ella majored in Elementary Education with a second concentration in Middle School Mathematics. During her participation in the redesigned educational technology course, she had her field placement at a 3rd grade classroom in an urban school. The school provided a variety of technology for teaching and learning. Her clinical educator often utilized Chromebooks, as well as an interactive whiteboard and a document camera for instruction. In addition to learning with technology in the classroom, her students received programming lessons once a week in the school computer lab. Ella's three CT-infused lessons were designed for lower graders in conjunction with her field placement teaching.

In her first lesson, Ella planned to use a game made on Scratch for 3rd graders to practice math questions related to place values in three-digit problems. In her second lesson plan, Ella integrated a concept mapping tool for 2nd graders to represent the water cycle (TPACK-CT). In her case report, Ella employed an online research component into a 3rd-grade social studies lesson (TPACK-CT).

After Ella completed her participation in the educational technology course, she entered her student teaching phase where she assumed increased teaching responsibilities while being supervised by her clinical educator. The duration of student teaching was two

consecutive semesters – one required for her elementary teacher education certification endorsement and one semester required for her middle school mathematics certification endorsement. In her first semester, she student taught in a 7th-grade middle school mathematics classroom at an urban school. The student population consisted mainly of African American and Caucasian students. Her classroom had an interactive whiteboard and the class used it every day. Additionally, a set of 25 Chromebooks was available for the whole grade to use upon request. However, Ella's class only got to use Chromebooks occasionally as "other classes needed it more." In her second semester, she student taught in a 3rd-grade classroom at a suburban school. The student population consisted mainly of Hispanic and Caucasian students. In this setting, she taught literacy (reading and writing) and math. Her classroom used an interactive whiteboard and Chromebooks every day.

Ella did not receive additional training related to CT. Although during the interview she was provided with a review sheet listing the CT concepts definitions, she roughly defined CT as "deeper thinking". Additionally, Ella failed to elaborate on how technology could be used to promote CT but overstressed that technology could promote learning in general. When she was asked to envision designing a CT-infused lesson with technology integration, Ella decided to use an interactive slideshow tool to engage students in deeper thinking about the topic.

Sophie's case. Sophie majored in Elementary Education with a concentration in Middle School Math. During her participation in the redesigned educational technology course, she had her field placement at a 4th-grade classroom in an urban school. The

school provided a variety of technology for teaching and learning. Her clinical educator often utilized Chromebooks and an interactive whiteboard to teach lessons. Her students also received a weekly technology special lesson in the school's computer lab, which was equipped with 40 Macbook desktops. Sophie's three CT-infused lessons during her participation in the course were designed for lower graders not exactly related to her field placement context.

For her programming lesson, Sophie used a Scratch game to help 2nd graders practice math concepts. In her second lesson plan, Sophie guided 2nd graders to decompose a math concept by constructing a concept map (TPACK-CT). In her case report, Sophie merged an online research assignment into her 4th-grade social studies lesson (TPACK-CT).

After Sophie completed her participation in the educational course, she entered her student teaching phase. Sophie first taught 7th-grade math in a suburban school. The dominant student population was African American and Caucasian students with a small percentage of Hispanics. Her classroom had an interactive whiteboard; however, the whiteboard was only used as a monitor since it was broken. In her second semester, Sophie taught 5th-grade core subjects including social studies and science in a suburban school. Her classroom used a variety of technologies every day including Chromebooks, iPads, an interactive whiteboard and a document camera.

Sophie did not receive additional training related to CT. During her interview, she did not specifically define or address CT for most of the answers. In addition, she was more comfortable in discussing technology integration to promote teaching and learning

without making a linkage with CT implementation. When she was asked to envision designing a CT-infused lesson with technology, she responded by using a Scratch game for students to practice mental math.

Technological, pedagogical and content representations in CT implementation (TPACK-CT). Ella and Sophie started with low TPACK-CT scores in their programming lessons. Their programming lessons used Scratch games for students to mechanically practice math problems. Their lessons did not manifest strong pedagogical, content and technological decisions in CT integration since the programming technology was not applied in relation to CT.

Despite starting with low TPACK-CT scores, the concept mapping lessons designed by Ella and Sophie showed improvement in representing TPACK-CT. For instance, Ella utilized Nearpod, an interactive slideshow, to distribute whole group instruction about the water cycle. Subsequently, the 2nd graders would individually create the process of the water cycle using an online concept mapping tool (TPACK-CT). Using concept mapping in this lesson can potentially support students' CT in the area of simulation (e.g., creating a representation of the water cycle) to facilitate understandings of the water cycle process. Sophie demonstrated a developing understanding of CT. She integrated the concept mapping tool in a kindergarten math lesson. Considering the students' age and technology background, Sophie decided to have the whole class complete one concept map displayed on an interactive whiteboard. In this activity, she steered the discussion, had different students express their thoughts about subtractions,

and documented and connected these ideas related to subtraction on the concept map (TPACK-CT).

Unlike the overall TPACK-CT trend (Figure 4.7) for the Low Start Group, which was decreasing at T3, the case reports of Ella and Sophie were closely aligned with CT implementation. Ella and Sophie employed similar procedures in designing and implementing their CT-infused lessons. Ella collaborated with another student teacher to teach a lesson which allowed students to conduct online research about an assigned geographic region (TPACK-CT). This lesson was designed based on multiple considerations, such as students' technological and content background, available classroom technologies and student behaviors. Ella and her partner made some pedagogical decisions in facilitating students' learning. For instance, they provided several credible links for students to conduct research online to avoid distraction from the internet. Additionally, they designed a graphic organizer to guide students through the research process, which included factual information (e.g., size and climate) and additional information determined by students. After students finished their research assignments, they presented their findings through creating an information poster. This lesson showed evidence in supporting students' CT knowledge and skills in problem decomposition, data and abstraction with the use of technology (Figure 4.9).

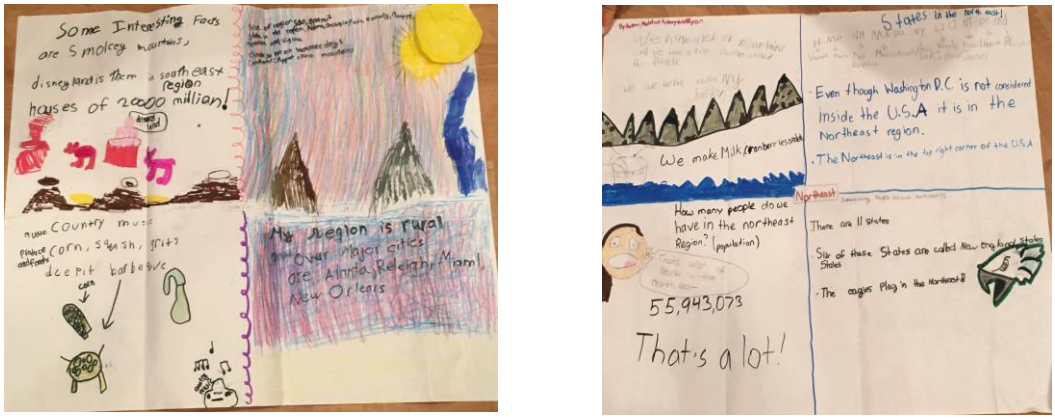


Figure 4.9 Student Posters Collected in Ella's Final Case Report.

Sophie implemented a CT-infused lesson into a 4th-grade social studies concept (TPACK-CT). Considering her class' technology background, content readiness and no behavioral issues, Sophie assigned students in groups and had them research a colony through the internet using Chromebooks. During students' research activity, Sophie walked around the room to monitor their progress. After students completed their research assignments, they used Google Slides to present their findings, following a model provided by Sophie (Figure 4.10).

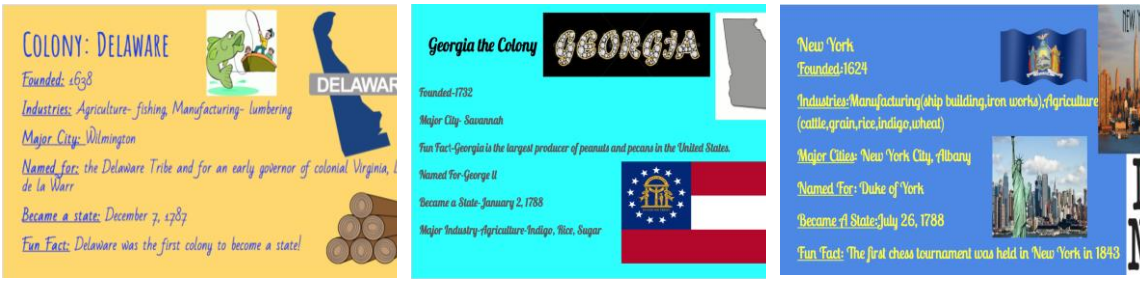


Figure 4.10 Student Posters Collected in Sophie's Final Case Report.

CT competencies (CT). The cases of Ella and Sophie reflect that they obtained shallow and somewhat inaccurate CT understandings at T1. Ella misinterpreted that her programming lesson supported students' CT because "students will be doing a visual

representation instead of just working through the algorithm" (T1). Sophie asserted that her lesson allowed students to solve problems which causally enhanced students' CT (T1). However, Ella and Sophie did not articulate how their lessons promoted students' CT at T2 and T3, even though their lessons included elements with the potential to support students' CT development.

From the interviews, Ella and Sophie appeared to be unfamiliar with CT at first. After they were reminded to review the CT concepts listed on the review sheet, they chose to discuss certain concepts, such as problem decomposition ("…problem decomposition. It's going to be math word problems, so the student is able to break them down and solve them step by step" (Sophie, T4)). For most of the conversation, Sophie was hesitant to provide details about how CT could be implemented in the classroom with a supportive and clear articulation. She merely mentioned how problem decomposition and algorithmic thinking could be used in math. Besides math, she had a hard time relating CT implementation with other subjects such as reading and writing: "I would think of abstraction (which) is hard for them (reading and writing). Automation and parallelization. I think those (abstraction, automation and parallelization) for things such as reading and writing. Obviously, I have such a strict curriculum so I can't see myself putting that (abstraction, automation and parallelization) into it (instruction)". Similarly, Ella did not provide additional justification about CT and its implementation in the classroom: "I used it (data) more with math because I had a chance to manipulate things more and show more diagrams and models to have kids think more deeply". Their understanding of CT did not improve substantially after they completed the course.

Sophie treated CT as a general problem-solving process, while Ella referred it as “deeper thinking”.

Attitude and knowledge related to computing technologies (TK-CT). The programming lesson of Ella reflected her limited knowledge regarding Scratch: as she mentioned in her lesson plan, her students “love[d] to create fun games with Scratch” and they were often observed to be “creating their own games and animations on Scratch during their free time in class”. However, Ella’s lesson did not leverage students’ strengths in programming. Instead, she introduced Scratch as a game for students and had them practice subtraction problems through “clicking and ungrouping” (T1). In fact, without having a full understanding of the Scratch software, most pre-service teachers underestimated the instructional time for equipping students with the necessary knowledge to produce programming products. For instance, Sophie did not actually introduce Scratch, however, she indicated that “I will first introduce Scratch as a “game” to help the students quickly do their math (addition and subtraction) mentally. I will show the students how you can use this not only for addition and subtraction but also multiplication and division as they work their way up” (T1).

Ella and Sophie demonstrated a stronger development in using concept mapping tools (T2). Ella’s concept mapping lesson integrated several technologies to promote students’ content and CT understandings, while Sophie’s lessons reflected her ability to navigate the concept mapping tool and embed it into designing a cohesive CT-infused lesson (Figure 4.11). Moreover, Ella and Sophie appeared to be familiar with the

technologies utilized in their case reports in order to design and implement strong CT-infused lessons.

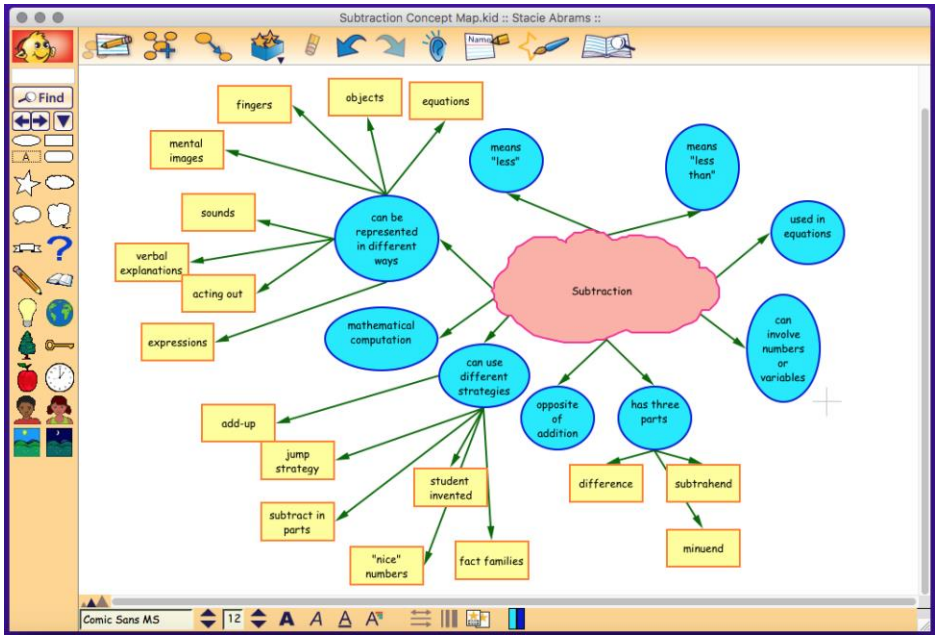


Figure 4.11 The Concept Mapping Example by Sophie.

From the interviews, Ella and Sophie retained vague knowledge related to computing technologies in promoting CT. However, their understanding of computing technologies, including their functionalities and applications, were not always accurate. Ella, for example, reported how she would use technology to support students' CT: "Like problem decomposition. I think that having technology can really help break down the information. So if students are confused, they have multiple different resources with the technology. They could use the smartboard. We record ourselves for a lesson before so they can go back to watch a video. I really think that can help students really understand what they are doing". Additionally, Ella reported that Nearpod and Kahoot were used to support students' CT development: "So we use a lot of things like Nearpod and Kahoot

which they [students] enjoyed because they [Nearpod and Kahoot] were very engaging for them and they like the competition. So all my students really enjoyed those activities when it came to technology because a lot of time it was like reviewing or even Nearpod you can teach a lesson on there. I taught a lot of lessons through Nearpod". Although Ella was provided with a review sheet with CT definition and learned computing tools from the redesigned educational technology lesson, her response did not accurately define and apply technologies to support students' CT. Similarly, although Sophie was able to define a computing tool (e.g., Smartboard) that could potentially be used to promote CT, she reported using the Smartboard as a visual representation tool instead of using it for CT-related activities: "I mostly use the interactive whiteboard every single day. A lot of time it's just smart notebook and something different for the student to see rather than just looking at a chalkboard or poster board or anything in that nature. A lot of time in math we will have them think the model on the board. For them to come up and do the work on the board. I feel that it allows students to engage in the class or each other".

CT implementation with contextual factors (TPACK-CT & Context). The final lessons of Ella and Sophie showcased strong TPACK-CT representations. It is worth mentioning that their lessons were designed with the technologies that their class had been using: "Our students are always using technology in the classroom. Each student has his or her own Chromebook in the class and knows how to look things up, make slideshows, and use the different tools" (Ella, T3). Their placements were equipped with various types of working technologies. Besides, their classroom teachers had integrated technologies into instruction which resulted in students' high proficiency in learning with

technologies. Furthermore, their students were at or above grade level and mostly had no behavioral issues. Although both cases addressed CT, Ella and Sophie did not recognize how their lessons supported CT. Therefore, their success in implementing CT in their case reports might not truly reflect their TPACK-CT trajectory. On the other hand, the cases of Ella and Sophie reflected that their classroom teachers, students and school environment had potential in influencing them into using technologies to promote CT in the classroom. This assumption was positively confirmed by their interviews.

When Ella and Sophie entered their student teaching phase, they were working with classrooms which were equipped with a variety of working technologies. Their interviews, however, revealed that they did not purposefully implement CT in these technology-rich contexts. In fact, there were several contextual factors that led to preventing them from synthesizing a CT-infused lesson, despite their limited knowledge of CT concepts and computing technologies. One of the factors related to how CT was valued in their student teaching placements. As reported by Ella and Sophie, CT was an unfamiliar concept for their schools and classroom teachers because this term was not mentioned on any occasions in the schools: “I feel like it [CT] is something that’s new and upcoming. We [pre-service teachers] get it because we go to the university with more research. It will be great for them [the classroom teachers] to get professional development” (Sophie, T4). Without acknowledging CT, the schools of Ella and Sophie did not intentionally value and implement CT, including integrating technologies into CT implementation: “If they [school administrators and classroom teachers] have the knowledge of that, it might make it a little bit easier for teachers to want to use

technology because they see all the benefits of CT and having kids do those things. They might be more willing to learn for the kids, which I think would be awesome. A lot of teachers I know in my school, they are so willing to learn and try new things which are really great. It really depends on the climate of the school a lot of times" (Ella, T4).

In addition, Ella and Sophie reported that students' background related to technology proficiency and behavior while using technology affected their decisions in integrating technology in their lessons. Their responses did not particularly relate to CT. However, these responses revealed that students' background could affect their decisions in implementing CT based on their decisions in utilizing technologies.

TPACK-CT representation of the Medium Start Group. This section provides an overview of the Medium Start TPACK-CT trajectory group. It first provides an overview of TPACK-CT for this group and subsequently presents results organized in four areas: representation of CT competencies, attitude and knowledge related to computing technologies, and contextual factors related to the implementation of CT in classroom settings.

Technological, pedagogical and content representations in CT implementation (TPACK-CT). Results of the one-way repeated measures ANOVA determined that the means of participants' overall TPACK-CT scores of the Medium Start Group significantly differed between time points ($F(2, 34) = 5.65$, $P = 0.008$). Post hoc tests using the Bonferroni correction revealed that participants' overall TPACK-CT scores were higher in the concept mapping lessons (T2) and final case narratives (T3) compared

with the Scratch programming design (T1). In particular, the difference of the mean scores of TPACK-CT between T1 and T2 was statistically significant. There was a slight reduction, 0.44 point, in participants' mean score of TPACK-CT from their concept mapping lessons to the final case narrative. However, this score deduction was not statistically significant (p = .29). Figure 4.12 below provides the boxplots of TPACK-CT scores among participants of the Medium Start Group at three different tasks.

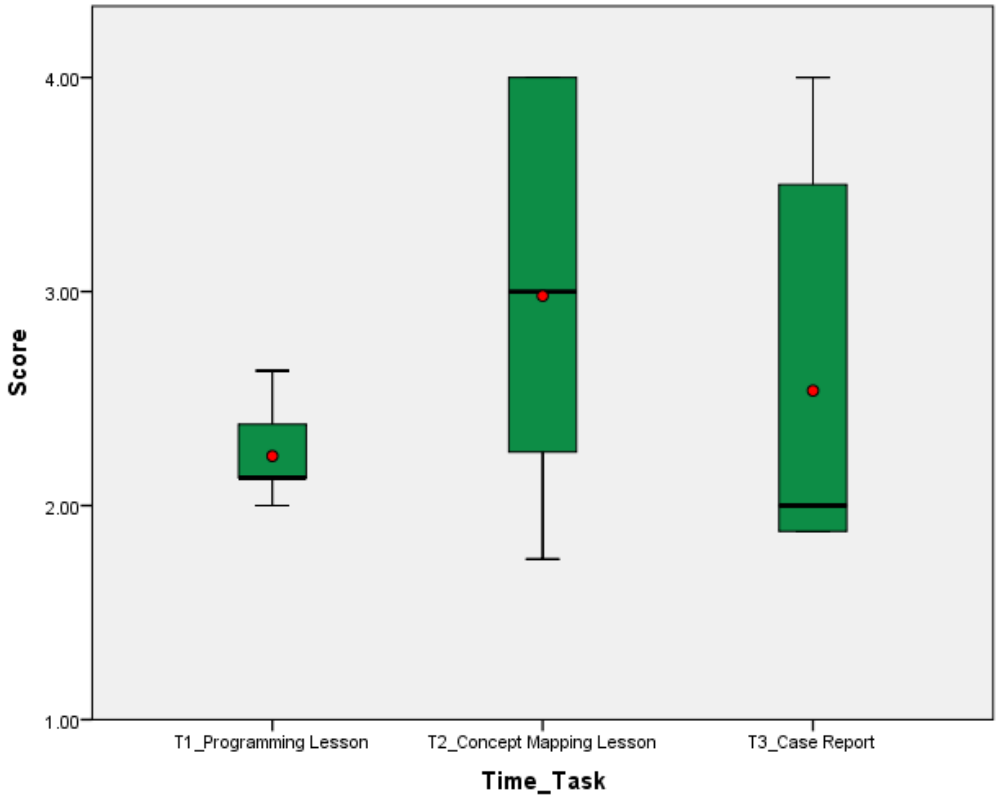


Figure 4.12 Boxplots of TPACK-CT Scores at Different Tasks for the Medium Start Group (N=18).

As shown in the quantitative results, pre-service teachers from the Medium Start Group started with a moderate TPACK-CT score at T1. The mean score of TPACK-CT became higher at T2 but slightly decreased at T3. Table 4.8 presents a summary of the grade levels and content areas addressed across the three lesson plans. As shown in

Figure 4.13, which presents a summary of CT practices illustrated in lesson plans, about a half of the lesson plans could be identified as reflecting certain CT practice (e.g., automation) although these activities needed further justifications. For instance, one lesson plan was found to be related to the CT practice of automation: "To solidify their knowledge about conversions while providing them with a way to check their answers, we want the students in our small group to code a metric conversion activity on Scratch, similar to this: https://scratch.mit.edu/projects/93452706/" (PST 10, T1). Additionally, this lesson plan briefly addressed the pedagogical approach (introduce the components of Scratch and have students complete the program in 30 minutes) and assessment (e.g., using the Scratch program to see if the conversions are correct) related to using programming in the concept of math measurement. Figure 4.13 reflects that pre-service teachers' lessons designed at T2 addressed a variety of CT practices compared to the lessons designed at T1 and T3. For lessons designed at T2, most pre-service teachers used concept mapping tools to promote students' content knowledge and CT understanding of data. Additionally, some pre-service teachers used concept mapping tools for helping students decompose concepts related to specific content areas, such as the writing process (PST 50, T2). At T3, about a half of the pre-service teachers were able to utilize computing technology in the design and implementation of a CT lesson, such as creating an interactive Smartboard activity for students to sort and organize data related to a content area (TPACK-CT). However, there were some lessons which used technology to support general learning activities which did not explicitly relate to CT. For instance, one pre-service teacher used the Smartboard to record students' responses to math questions:

"Within my lesson, I decided to include students more interactively with the SMART Board and overall math lesson by having three students come up to the board and use the SMART Board pens to draw out their math strategies on the board" (PST 30, T3).

Table 4.8 Overview of the Lesson Design Products of the Medium Start Group.

	T1_Programming Lesson Plan	**T2_Concept Mapping Lesson Plan**	**T3_Case Report**
Content Area			
Math	33%	6%	28%
Science	6%	11%	61%
Social Studies	11%	33%	11%
Literacy	50%	50%	-
Grade Level			
K -2nd Grade	22%	17%	17%
3rd -5th Grade	72%	72%	83%
6th -8th Grade	6%	11%	-

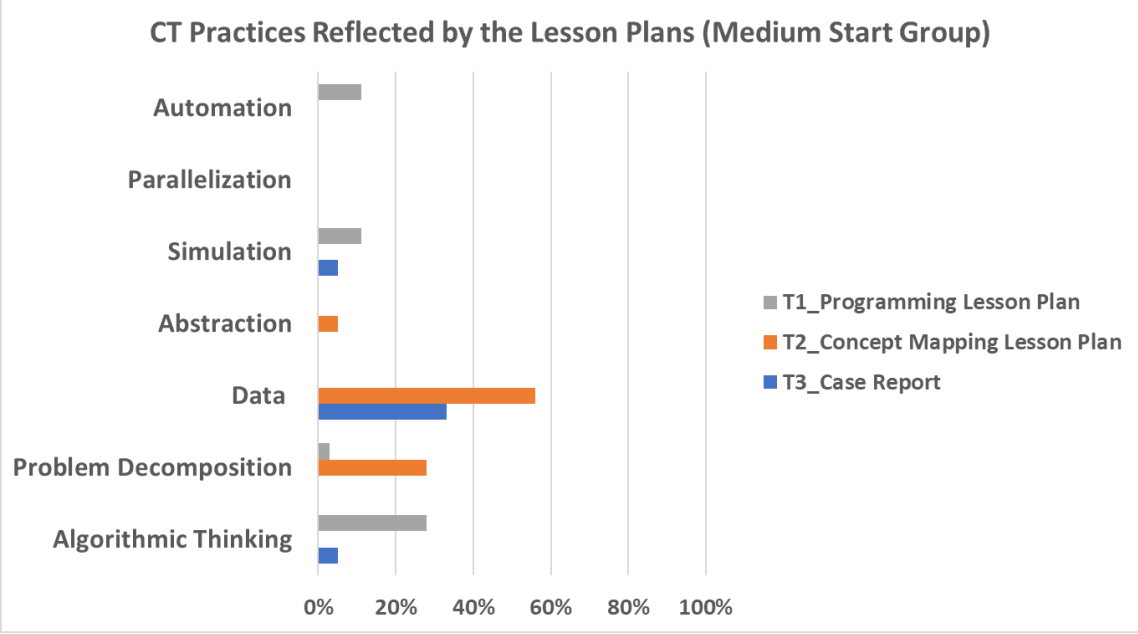


Figure 4.13 CT Practices Reflected by the Lesson Plans (Medium Start Group).

CT competencies (CT). Results from pre-service teachers' CT-infused lesson plans indicated that they initially exhibited developing yet thorough understandings regarding CT. According to Table 4.9, more than 50% of the pre-service teachers were able to articulate the CT practices addressed by their programming lessons, such as using specific CT vocabulary or defining CT as a general problem-solving process. For instance, one pre-service teacher explained how her programming lesson could promote students' CT: "The programming aspect of this lesson allows the student's computational thinking skills to flourish by having the student use an algorithm to piece together smaller parts of the project in order to create the presentation as a whole" (PST 34, T1). Similarly, about 55% of the pre-service teachers addressed CT in their concept mapping lessons by either using CT vocabularies or providing explanations related to CT concepts such as organizing and analyzing data: "[Using a concept map] it's not that the students are just putting the events on a timeline, they are analyzing the events and looking at the impact they had on each other" (PST 51, T2). The pre-service teachers of the Medium Start Group continued to hold moderate CT competencies in their T3 lesson plans, since more than 60% of them were still able to provide a general explanation related to CT, as shown in Table 4.9 below.

Table 4.9 CT Competencies of the Medium Start Group.

CT Competencies	**T1_Programming Lesson Plan**	**T2_Concept Mapping Lesson Plan**	**T3_Case Report**
Using CT vocabularies or providing an explanation related to CT concepts	28%	55%	33%
Viewing CT as Problem Solving Skills	33%	17%	39%
Not Mentioned/ Not Related/ Unclear	39%	28%	28%

Attitude and knowledge related to computing technologies (TK-CT). It was not surprising that over 50% of the pre-service teachers found learning to program on Scratch to be challenging since they obtained no or very limited experience of programming. Although most of the pre-service teachers found learning Scratch to be difficult, 73% of the pre-service teachers supported the idea of introducing programming in their classroom. In fact, some of them even provided analytical thoughts about how to potentially infuse programming in the classroom. As one of the pre-service teachers reflected, she had difficulties programming in Scratch without having any previous programming experience and therefore she thought it was important for teachers to receive more support about Scratch before introducing it to the students:

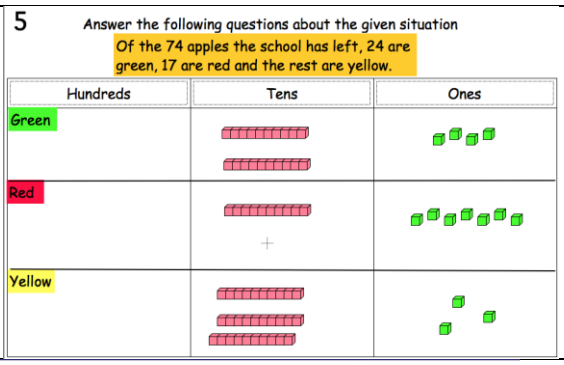
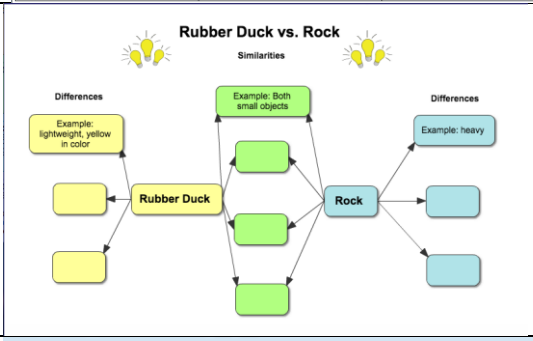
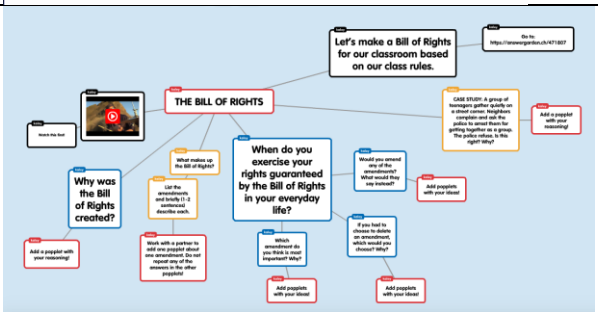
> "I find programming to be rather difficult, even when Scratch tries to simplify it into easier step by step components. I found myself to be having a difficult time when it came to create a file with multiple backgrounds and many different things going on. Looking at the sample lessons, I thought I would have an easy time creating a complex presentation, but this was not the case. I think I would personally most benefit from Scratch by using a premade lesson. This would allow me to customize it to my liking but would not require me to go through the struggle of having to create something from the bare with many different components. I did enjoy my experience with Scratch, but I would definitely not

> say this is made for someone who has no programming experience. I believe that in order to be successful with this program, much introduction would be necessary for a new teacher to be able to use this website to teach children the basics of coding. With that being said, I do think that these premade lessons will allow children to learn coding in a way that is fun to them and without them even realizing that they are coding" (PST 19, T1).

Nearly all pre-service teachers in this group were able to obtain a basic understanding of using the Scratch software, which was reflected by their pedagogical approaches related to equipping students with programming skills. About 50% of the pre-service teachers provided a brief introduction about Scratch while the other half of the pre-service teachers asked students to explore the Scratch website or to watch some tutorials to gain some knowledge about the technology. For instance, one pre-service teacher proposed to start her class with a whole class introduction about Scratch to ensure every student acquired some knowledge related to using Scratch. Subsequently, she would model an example of how to program on Scratch for her students (PST 6). Compared with their knowledge about Scratch, pre-service teachers became more proficient in navigating the concept mapping tool. About 72% of them provided a concept map example which was used to model to students about how to assimilate with the tool (Table 4.10).

Table 4.10 Concept Mapping Examples of the Medium Start Group.

PST ID	**Subject Area**	**Concept Map Example (72% of the PSTs of the Medium Start Group created a concept map for their lesson).**	**Supported CT Practice (Defined based on the Learning Goals and Lesson Activities)**

6	Math		Problem Decomposition
22	Science		Data
10	Social Studies		Data

Noticeably, the pre-service teachers in the Medium Start Group demonstrated unequal understandings related to computing technologies in their final case reports. This phenomenon was reflected by their selection of technologies for designing and implementing CT lessons. According to Table 4.11 below, 65% of the pre-service teachers were able to select a technology which had the potential to be used for computing, such as Smartboard and Scratch. Their selected tools were found to be the ones that were introduced by the redesigned educational technology course. For instance, one pre-service teacher implemented Smartboard into her science intervention for

students to sort different science-related objects (PST 32, T3). Although the pre-service teachers chose to integrate interactive whiteboards (e.g., Smartboard) that could potentially promote CT, their lessons did not achieve such a purpose by using the Smartboard to display worksheets or PowerPoints (PST 6 & 46, T3). Additionally, a number of the pre-service teachers selected technologies which couldn't be categorized as computing technologies, such as the visual presenters (e.g., Elmo).

Table 4.11 Selected Technologies for Final Case Reports of the Medium Start Group.

Technology	**T3_ Case Report**
Interactive Whiteboard	50%
Google Classroom	5%
Kahoot	17%
Internet for Research	10%
Scratch	5%
Elmo Projector	10%

CT implementation with contextual factors (TPACK-CT & Context). As the pre-service teachers designed hypothetical lessons at T1 and T2, they focused more on the design of the lesson activities (e.g., lesson components). In contrast, the pre-service teachers' final lesson plans addressed more about the contextual factors, including students' background knowledge, given instructional time and so forth. For instance, one pre-service teacher (PST 10) proposed to design a programming lesson (T1) which had the students create a metric converter using Scratch. Her lesson plan provided a very general description of how Scratch could be introduced to the students yet did not provide enough details to support her pedagogical decisions (PST 10, T1). In her final case report, she expanded this programming lesson and implemented it with a small group of three students during a math intervention section. One of her updated components of the lesson

related to her pedagogical decisions about helping students without programming background to familiarize with Scratch: “At the beginning of the lesson, we had to show the students where many of the components were, and how to use them (for example, we had to show them where the script buttons were, where to drag them, and how to connect them)” (PST 10, T3). Moreover, she provided detailed steps and instructions to guide students through the process of creating the converter as shown in Figure 4.14.

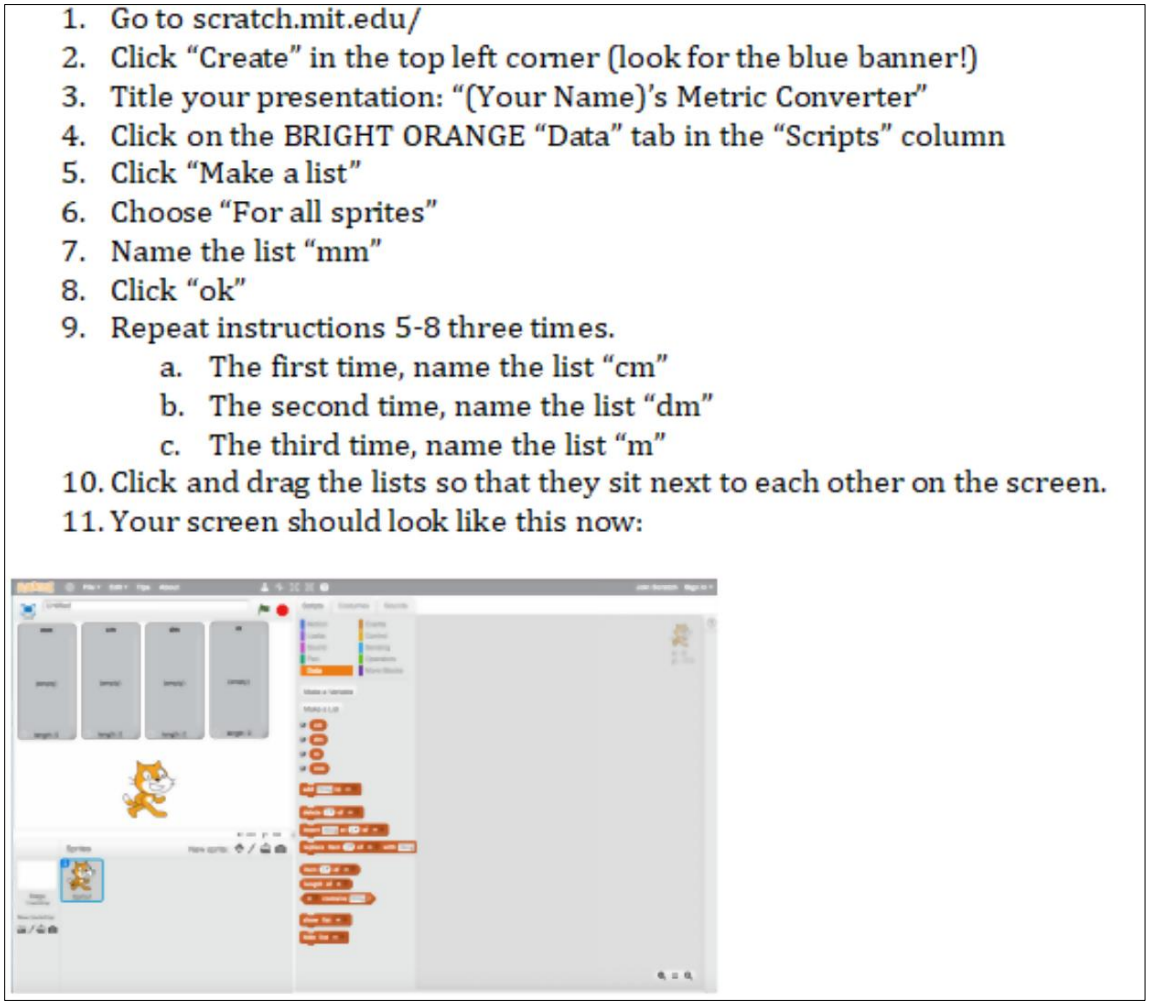


Figure 4.14 Example of Programming Instructions by PST 10.

In fact, teaching students without any programming background to complete a project that involved many advanced programming features would be challenging. As PST 10 reported, the lesson did not get to finish since the instructional time was limited and the students needed more support in becoming familiar with navigating Scratch. Therefore, the pre-service teachers' CT implementation could be influenced by contextual factors. As shown in Table 4.13, although the pre-service teachers were required to teach a CT-infused lesson with technology integration, the majority of the lessons focused more on using technology to support general learning activities which were not specifically CT-related.

Table 4.12 Purposes of Integrating Technologies for Final Cases of the Medium Start Group.

Using Technology for	**T3_Case Report**
Supporting CT and Content Understandings	40%
Representing Instructional Materials	27%
Assessing Learners' Knowledge	30%

Medium Start Group Representative Cases. This section describes two representative cases of the Medium Start Group TPACK-CT trajectory group following the same format as the Low Start Group.

Jane's case. Jane majored in Elementary Education with a concentration in Special Education. During her participation in the redesigned educational technology course, she had her field placement at a 4th-grade classroom in an urban school. The school provided a variety of technology for teaching and learning. There were 25 laptops and 3 desktop computers in Jane's classroom. Additionally, two iPads and one

Smartboard were available in her classroom. There was a computer lab which had 25 computers; however, the lab was rarely used. Jane's three CT-infused lessons were designed specifically for 4th graders for her field placement.

Jane used a Scratch game for students to practice a geometric concept. Additionally, her lesson incorporated a component which allowed students to program their own geometric shapes (TPACK-CT). In her second lesson plan, Jane used a concept map to help students review a geographic concept (TPACK-CT). In her case report, Jane utilized various types of technologies in learning activities which, however, were not strongly related to CT implementation.

Jane student taught in two classroom settings. She first taught in a 1st-grade classroom with core courses (Social Studies and Science were not offered in school) in an urban public school, with a population of 96% African American students. The school was not equipped with adequate working and available technology. In her second semester, Jane taught 3rd and 4th-grade special education in an urban private school which had 80% Caucasian, 10% Asian and 10% African American students. This school provided different technologies for teaching and learning, including Smartboard. Students had their own laptops. Additionally, students received weekly technology special to learn how to use technology and STEM-related activities such as coding. Teachers in this school did not need to follow a specific curriculum and had more flexibility to design and teach lessons.

Jane did not receive additional training related to CT. She was prepared for the interview – she indicated that she reviewed and took some notes based on what were

listed on the review sheets. During the interview, Jane provided examples related to her teaching experience about how CT could be implemented in the classroom. Additionally, Jane was able to relate how CT was supported by specific technology listed on the review sheet. Jane, however, did not continue to show accurate understanding about how technology was used to facilitate CT when relating to her own teaching. In terms of designing a CT-infused lesson in her future classroom, Jane changed her decision from simply using some educational applications to embedding a concept mapping tool to facilitate CT implementation.

Lily's case. Lily majored in Elementary Education with a concentration in Middle School Math Education. During her participation in the redesigned educational technology course, she had her field placement in a 5th-grade classroom. The entire 5th grade shared a cart of 27 laptops. In Lily's classroom, one of three student computers was broken. Additionally, her classroom was equipped with two teacher laptops and a Smartboard. Her students received a technology special once a week in the school computer lab, which had 90 Chromebooks and 12 desktops. Lily's lesson plans were developed for upper-grade levels in conjunction with her field placement.

Lily proposed to integrate programming for her 5th graders to create geometric shapes (TPACK-CT). In her second lesson plan, Lily planned to engage the whole class to decompose the properties of shares through constructing a concept map (TPACK-CT). In her final case report, Lily created a Smartboard activity for her students to sort information related to a science topic (TPACK-CT).

In her first student teaching semester, Lily taught 7th-grade math in an urban public school. The student population was primarily African American. The available classroom technology included a document camera and a Smartboard. In her second student teaching semester, Lily taught 4th-grade core subjects in a rural public school. Her classroom was equipped with a document camera and a Smartboard.

Lily did not receive additional training related to CT. She was able to provide some examples of how CT could be integrated into the classroom, using her own teaching examples. However, Lily's answers related to how technology could be used to support students' CT merely connected to the technologies that she had been exposed to in her student teaching placements. When Lily was asked to envision how to integrate CT with technology in her future classroom, she referred to what she had learned from the redesigned technology course and brought up several ideas such as using the play dough circuits to teach a science topic related to electricity.

Technological, pedagogical and content representations in CT implementation (TPACK-CT). Lessons designed by Jane and Lily demonstrated that they were able to design TPACK-CT to some extent. Jane's programming lesson reflected an emerging representation of TPACK-CT. She envisioned using a Scratch game for students to practice calculating the area and perimeter of rectangles. Subsequently, students would create their own shapes using Scratch and let their partners solve the area and perimeter of these shapes. Jane, however, did not provide other details about pedagogies related to the lesson implementation. Similarly, Lily proposed to have her students program their own geometric shapes. She focused more on facilitating students' content readiness in

programming their geometric shapes but did not address pedagogical decisions such as approaches to preparing her 5th graders for programming on Scratch. Although Jane and Lily represented the pre-service teachers from the Medium Start group, their individual TPACK-CT trajectory divided into two trends after the concept mapping lessons.

Jane used a concept mapping tool for students to review information about geography. She planned to display a concept map on an interactive whiteboard and have students review and discuss the geographic concepts. As Jane explained, the concept map supported students to review a familiar concept (e.g., geography) by providing relevant ideas and examples, which was aligned with CT concepts in decomposition. Lily proposed to have the 4th graders discuss the properties of shapes and simultaneously construct a concept map. Students would share what they knew about the topic while Lily facilitated the discussion and organized students' responses into a concept map. Lily's reflection about how this lesson supported students' CT (e.g., "(Concept mapping tool) requires students to build upon their background knowledge collectively in order to reach the learning goals of this lesson") was related to a CT concept in decomposition.

In the final case reports, Jane and Lily demonstrated different TPACK-CT developmental branches. Jane integrated different types of technology and interesting activities into her lesson, however, none of these learning activities were strongly connected to CT. In particular, she used Kahoot, which was a new technology for her class, for the pre- and post- assessments of her science lesson. During her lesson, she used the Smartboard to display two videos to demonstrate the process of photosynthesis. Finally, students were given different materials such as cotton balls to create a poster of

the process of photosynthesis. The technologies used in this lesson did not support CT. Moreover, Jane did not provide an accurate explanation about how this lesson supported students' CT, instead, she assumed using technology in the lesson could automatically enhance students' CT: "This lesson supported the development of students' computational thinking skills because they used technology in order to complete the lesson. Not only did students learn that they can answer questions in a fun, interactive format online, but they also watched educational videos that demonstrated the topic they just learned about. Without watching the different real-life plants in action, the entire worksheet and discussion going along with it would have been non-existent. Students acquired so much knowledge by watching the plants produce their own food and adapt to different surroundings in a way they would never be able to fully see without watching it happen right in front of them on video". Therefore, Jane's lesson reflected a relatively limited CT implementation. The lesson plan and implementation reflected that Jane did not obtain an accurate understanding about knowledge and skills related to CT concepts and computing (TK-CT). Therefore, albeit making use of different types of technology in this classroom, her lesson did not manifest TPACK-CT integration.

The TPACK-CT implementation of Lily's final case represented her continuous growth in leveraging technology for CT implementation. Considering the school science curriculum and students' content readiness, Lily collaborated with her teaching partner to teach a 5th-grade science lesson using the interactive Smartboard. In particular, they created an interactive activity on the Smartboard for students to sort, organize, compare and contrast objects, as illustrated in Figure 4.15 below. Students were invited to use the

Smartboard to demonstrate ideas and generate discussion about their sorting. As Lily reported, the lesson was interactive and engaging and "the use of technology helped students visualize the differences between the models and compare and contrast the different possible outcomes". Lily was able to provide an analysis about how this lesson supported students' CT related to data: "The lesson supported the development of students' computational thinking skills, as it required students to sort aspects of the model and also partake in a simulation of an everyday occurrence. Furthermore, this lesson required students to problem solve of how to combat the natural occurrence of erosion using scientific observations that could be used to reason for a solution. Furthermore, students were also asked to investigate designs that can counteract the effects of erosion such as beach-grass plantation, development ponds, etc."

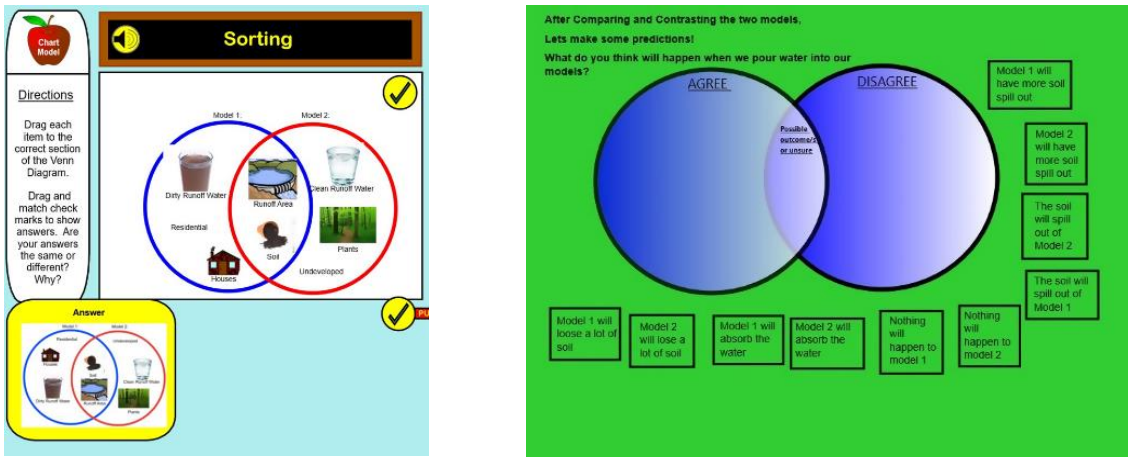


Figure 4.15 The Smartboard Activity Designed by Lily.

CT competencies (CT). Jane and Lily demonstrated moderate CT understandings, in that they could provide a general explanation about CT yet could not provide detailed elaboration. Jane asserted that her lesson supported students' CT through problem-solving using the programming tool (T1). Likewise, Lily briefly indicated that her

programming lesson supported students' algorithmic thinking and problem-solving skills (T1). At T2, Jane and Lily showed progress in describing how their lesson supported CT related to decomposition. However, Jane did not correctly articulate CT in her final case (T3), while Lily continued to show development in CT understandings in her case (T3).

From the interviews, Jane and Lily mechanically referred to the review sheet as they explained CT. They were able to define and instantiate CT concepts, with a focus on problem decomposition, algorithmic thinking and data. Noticeably, their elaboration of CT concepts triggered their connections about how CT was implemented in their classroom. For instance, Jane explained how problem decomposition was related to her own teaching

> "I actually took notes when I think to use them [in the classrooms]. For a) [listed in the review sheet], it says it's problem decomposition, so breaking down a complex problem into manageable parts. I personally built this like for writing, I don't know if I am right. I was thinking that because you tell a student to write, like a first week essay or something, which is actually one of the lessons I taught last week. I found that it worked to use as a graphic organizer to break up the parts, to think OK this is the beginning of your writing, and it needs to include the topic and opinion, then this is the body of the essay, which is to include like three reasons with evidence to support it, and then this is the ending so your conclusion that needs to restate the topic or opinion." (Jane, T4)

Likewise, Lily provided an explanation about CT followed by an example:

> "Number two, algorithmic thinking. We even try like a new skill like we recently considered long division. That was very algorithmic thinking. We gave students a pre-thinking part where they had to come up with numbers, I would work with what they are working with depending on the problem. But my students, they have to follow these steps. When we grade their work, we have to see those steps in order to give them full credit".

Jane and Lily were able to conceptualize CT and connect CT into their teaching practices. However, their CT competencies were not solid. In particular, when they were

asked to provide examples related to CT implementation using technologies in their own classrooms, their answers merely focused on how technologies could be used to facilitate instruction and learning and neglected the role of CT.

Attitude and knowledge related to computing technologies (TK-CT). Jane and Lily were able to recognize the potential of Scratch by integrating programming into their lessons. However, since they did not obtain solid understandings about CT, their lessons provided inadequate pedagogical decisions related to teaching/integrating the programming technology. For instance, Jane's lesson did not contain a formal introduction section about Scratch such as addressing how students would be guided to acquire programming skills. Lily's lesson proposed to provide a 15-minute Scratch introduction to her students (T1). However, Jane and Lily demonstrated to be more knowledgeable in using concept mapping and both of them provided a concept mapping example in their lesson plan (Figure 4.16).

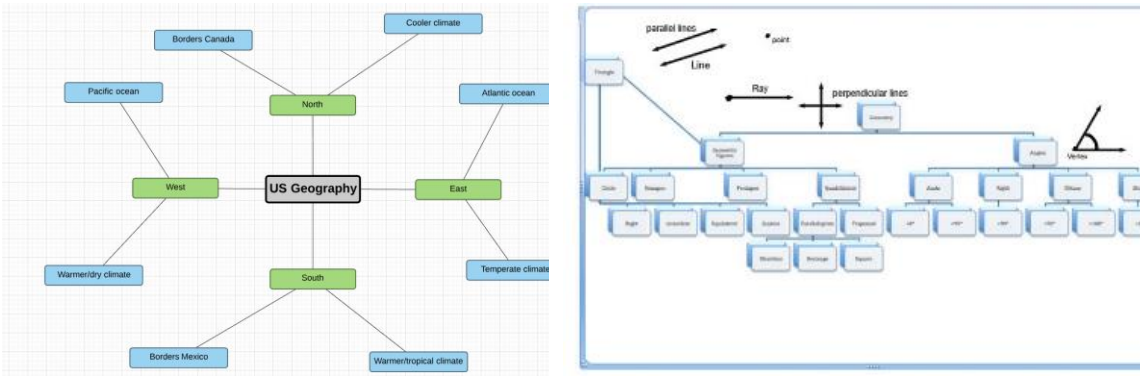


Figure 4.16 The Concept Mapping Examples by Jane (Left) and Lily (Right).

The final cases of Jane and Lily showed that Lily gradually strengthened her knowledge related to computing technology, while Jane showed the opposite side. Both

Jane and Lily used an interactive whiteboard in their final lessons; however, Lily used the Smartboard to promote students' CT while Jane used it as a visual representation tool to promote students' engagement.

In their interviews, Jane and Lily were able to recognize and define computing technologies listed on the review sheet, such as programming tools, concept mapping tools and interactive whiteboard. For instance, Jane retrieved her learning experience related to using a programming tool after reading the review sheet: "I remember in the class [redesigned educational technology course] when I was reading through the sheet, I remember we did a programming game, where you learn how to make your own game" (Jane, T4). However, their knowledge related to the applications of computing technologies was not comprehensive, especially when they were asked how to integrate the defined computing technology into their classroom. For instance, Lily was able to define the interactive whiteboard as a computing technology. Her justification about how to use the interactive whiteboard to implement CT, however, did not relate to any CT concepts: "[Smartboard] It is probably the easiest to me to use in my classroom because it is provided in the classroom and students are used to it. In fact, students have used it most of the time. I like the fact that it can be used as a screen and also like a big computer, so I am able to show a lot of videos on it. And we can apply that to our own thinking. I didn't really use many programming in my classroom" (Lily, T4).

When Jane was asked to envision how she would design a CT-infused lesson plan with technology integration, she originally wanted to use some educational apps to facilitate students' reading comprehension. However, she changed her original plan and

sought to use an online storyboard for students to represent the story with main ideas (abstraction):

> "I am thinking maybe I can actually use the story board thing that we used online in the class [redesigned educational technology course] to have them summarize it, because a lot of times they just answer questions. But now when I am thinking on it, I am trying to think I might plan them to do it online, and it's easy to do it because they have their own computer which is provided by the school. So it would be easy for me to show them on the smart board how they get to the website and they could follow along and then they could do it themselves too".

The above example illustrates Jane's increased awareness of using computing technology to support students' content and CT knowledge. Likewise, when Lily was asked to envision how to integrate CT with technology in her future classroom, she referred to what she had learnt from the redesigned technology course and brought up several ideas. For instance, she talked about using play dough circuits to teach science:

> "What I remember in the course that we used for… it was like different color of play doughs and depending on what wire you put into the play doughs it would either create like a light or sound. I think the colors were blue and pink… If I was able to do a lesson on that, I will definitely try to say give me hands-on, some kind of tool such as that to show. Just let my students see hands-on example l of electricity".

Furthermore, she talked about using Finch Robot for a math lesson: "That (Using robotics) would be good to associate if you dive into graphing to show how to coordinate a graph to show or realize the implementation of it".

CT implementation with contextual factors (TPACK-CT & Context). The cases of Jane and Lily reflected that contextual factors influenced their decisions in planning CT-infused lessons in classroom settings. Jane's decisions in integrating CT into instruction largely depended on her teaching context, such as students' experience with technology. In Jane's final case report, she reported that most of her students did not have much

experience in using technology – students used to solely work on worksheets and rarely used technology. Based on these contextual factors, Jane and another student teacher decided to integrate technology into their 4th-grade science lesson to provide the students with an engaging learning experience. She integrated different types of technology with designed learning activities to engage students in learning, however, none of these learning activities were strongly connected to CT. Jane's lesson represented her decisions about using technology to engage learners in learning activities, which was the result of contextual factors. Likewise, the final case of Lily reflected that her CT integration was designed based on an analytical consideration of contextual factors in her classroom. Such contextual factors include the content requirement (e.g., "our science course required a scientific demonstration").

During the interviews, Jane and Lily indicated that their teaching techniques related to using technology and pedagogy were influenced by how and what their classroom teachers taught in the classroom: "my clinical educator this semester already does this kind of stuff [using Smartboard], so it made it easier for me because I got to see how he did it first and I can follow along" (Jane, T4). Therefore, the classroom teachers' mindset and knowledge related to technology and CT appeared to be an important factor for pre-service teachers to implement these concepts into instruction. In fact, Jane and Lily mentioned that teachers' mindset and knowledge related to technology could affect their decisions about CT integration. As Jane said: "a lot of teachers if they are older and they haven't been exposed to technology, it may almost intimidate them because they may not know how to use it. I think for some teachers if they don't know how to do it,

they may not really want to learn, and this turns them away from it. So I think that a lot of time that also plays a role in whether or not the teacher uses it, because if they are not familiar with it they may be less likely to try". Similarly, Lily reported: "I think there is always like that the age relation with some teachers who have been teaching for a long time. They don't want to change their method. With more current teachers, there is an idea of always working for more ideas knowing they are coming out there. …it is a little bit of both depending on the teacher, like how they think their students learn best. Also, I think if you realize that your students learn better using a more traditional way, then you will stick to that, just for some students that are just more appropriate and beneficial".

In addition, access to available and working technology became a factor to influence pre-service teachers' decisions in CT implementation. For instance, Jane had worked at the school which shared one laptop cart for the whole school and the laptops were old and "barely working". Although a Smartboard was available to use in Jane's classroom, it was "only to be used for PowerPoint that was especially for those lesson plans that were given to us. So we have the Smartboard but they [lesson plans/PowerPoint] were used for a whole lot". Similarly, Lily indicated that a broken Smartboard was the only available technology in her classroom: "there is no interactive tool". Working with limited and not working technology hindered Lily's decision in CT implementation in her classroom because she could only use the Smartboard as a projector. In fact, when Lily was given an opportunity to design a CT-infused lesson in a technology-enriched environment, Lily referred to what she had learned from the

redesigned technology course and brought up several ideas, such as using play dough circuits or robotics for CT implementation.

Moreover, Jane and Lily reported that a demanding school curriculum resulted in having limited instructional time to complete learning activities, and therefore they did not have the flexibility to implement CT in their placements. For instance, Lily found it would be challenging if she would implement an Hour of Code lesson for her class: "I think for most districts, right now it is hard to say "well we are going to take an hour out of what you are doing and do something like that", especially in spring semester right now. My kids are testing after today for 8 days straight. It's hard to find an hour block". However, although some schools/districts did not particularly advocate CT, they had showcased some actions related to CT. For instance, Jane provided a convincing example of how CT was infused in the classroom through a school effort: "Last semester, because I was teaching in the inner city, and attendance was very low. What they started to do was they started to have us take like we have a whiteboard outside the classroom, and we write down our percentage of students who were present, and then we would kind of make a chart in excel, and we would show our students and class, like the trend kind of was as our class attendance. We would look at the attendance and then when we look at it in the chart, we saw it is improving, then there is a reward for them, so we use it in a way to show the trend. And then I was thinking like other statistics, if you [are] researching things in statistics class and different math classes, even something like you are following weather pattern in science class or something, you use data collection and you analyze it, and show it through the data and image and stuff like that" (Jane, T4)".

TPACK-CT Representation in High Start Group. This section provides an overview of the High Start TPACK-CT trajectory group. It first provides an overview of TPACK-CT for this group and subsequently presents results organized in four areas: representation of CT competencies, attitude and knowledge related to computing technologies, and contextual factors related to the implementation of CT in classroom settings.

Technological, pedagogical and content representations in CT implementation (TPACK-CT). Results of the one-way repeated measures ANOVA determined that the means of participants' overall TPACK-CT scores of the High Start Group significantly differed between time points ($F(2, 16) = 9.16$, $P = 0.002$). Post hoc tests using the Bonferroni correction revealed that participants' overall TPACK-CT scores remained consistent in the concept mapping lessons (T2) and final case narratives (T3) compared with the Scratch programming design (T1). However, as demonstrated by Figure 4.17, there was a dramatic reduction, 1.06 point, in participants' mean score of TPACK-CT from their concept mapping lessons to the final case narrative, which was statistically significant ($p = .013$). Figure 4.17 below provides the boxplots of TPACK-CT scores among participants of the High Start Group at three different tasks.

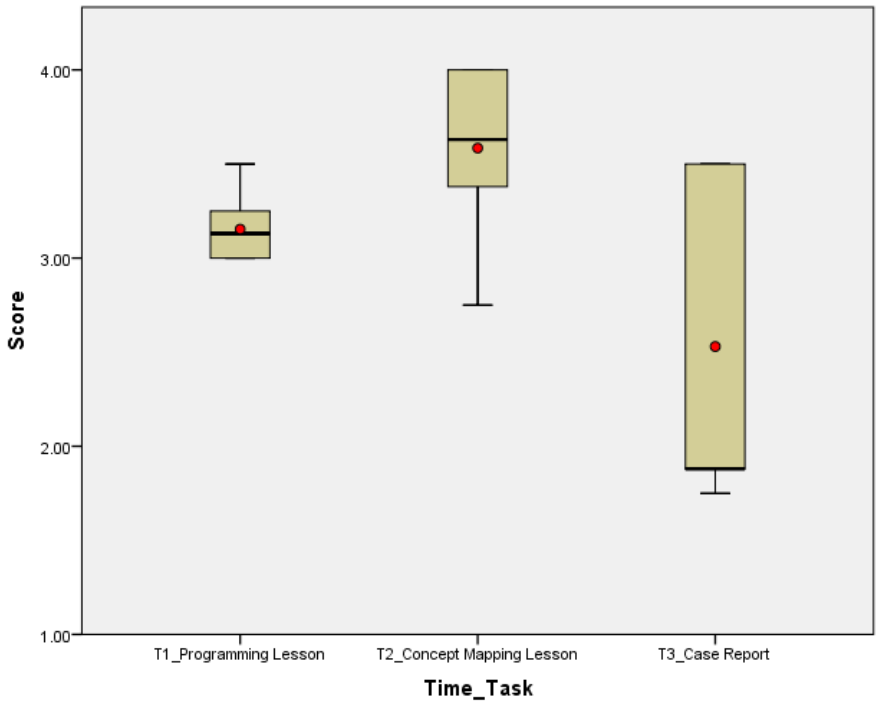


Figure 4.17 Boxplots of TPACK-CT Scores at Different Tasks for the Low Start Group (N=9).

As shown in the quantitative results, the pre-service teachers from the High Start Group started with a high mean score of TPACK-CT score at T1 and remained stable at T2 but the mean score of TPACK-CT decreased at T3. Table 4.15 presents a summary of the grade levels and content areas addressed across the three lesson plans. Figure 4.18 presents a summary of CT practices extracted by the author. From the data shown in Table 4.15 and Figure 4.18, the pre-service teachers from the High Start Group were competent in designing TPACK-CT lessons for various subjects across different grade levels and supporting students' CT development, particularly at T1 and T2. Especially, they demonstrated a stronger-TPACK-CT instantiation to support students' CT and content understandings with different pedagogical strategies. For instance, PST 20 proposed to integrate programming to one small group during a math intervention

sections to help students create geometric shapes using Scratch (T1). In particular, the integration of programming in this lesson was to have students design Scratch projects to automate the creation of geometric shapes such as regular pentagons or polygons (automation). Considering her instructional time and students' knowledge related to the content and programming, PST 20 estimated that her lesson implementation time would be over one week to ensure students can fully complete the program. Additionally, she adopted various pedagogical approaches for implementing this lesson. Table 4.13 reflects that pre-service teachers from the High Start Group were able to address CT practices in their lessons at T1 and T2. However, only about 50% of them were able to design and implement lessons in relation to CT in the classrooms (T3). The pre-service teachers whose lessons were not aligned with CT showed weak connections between CT practices and the use of computing tools (e.g., used an interactive whiteboard for presenting the content).

Table 4.13 Overview of the Lesson Design Products of the High Start Group.

	T1_Programming Lesson Plan	**T2_Concept Mapping Lesson Plan**	**T3_Case Report**
Content Area			
Math	33%	22%	-
Science	55%	11%	55%
Social Studies	11%	22%	33%
Literacy	-	44%	-
Programming	-	-	11%
Grade Level			
K -2nd Grade	22%	44%	33%
3rd -5th Grade	66%	44%	66%
6th -8th Grade	11%	11%	-

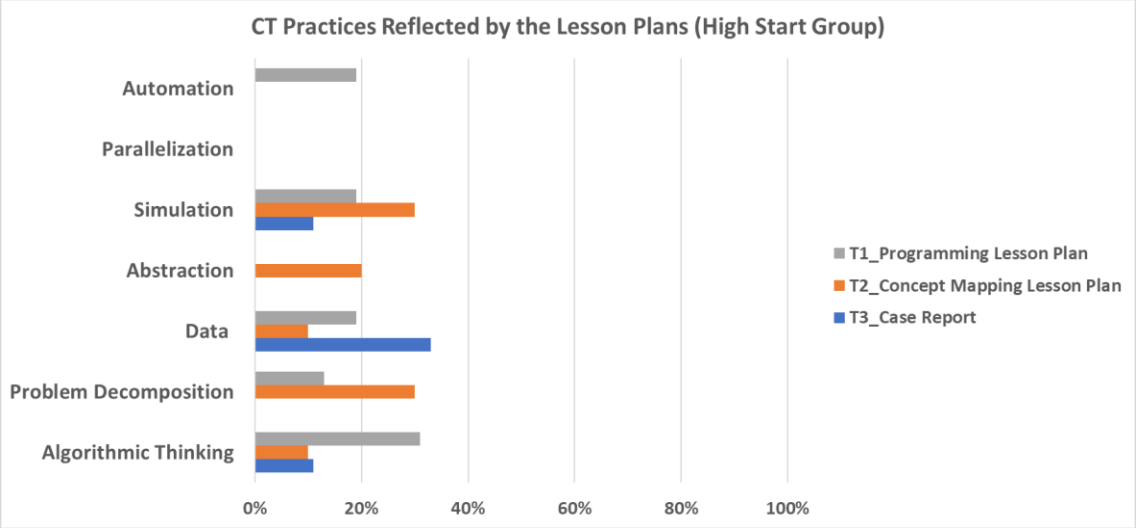


Figure 4.18 CT Practices Reflected by the Lesson Plan (High Start Group).

CT competencies (CT). The pre-service teachers from the High Start Group were able to leverage CT vocabularies or explain relevant CT ideas in their CT-infused lesson plans at T1 and T2. According to Table 4.14 below, about 90% of the pre-service teachers were able to address and articulate CT in their programming lessons (T1). Moreover, they often provided a detailed explanation about how CT was addressed in their lesson by connecting certain CT practices with the content objective: "Through the process of scripting a story with 3 events and 2 different forms of transportation, the students will be using the sequencing skills in their writing even before they use Scratch. This connection to the sequencing mindset that is needed to program things is very important. The lesson allowed for a relation to how computers think and how we can tell computers what to do. I think that especially during second grade it is important to be very broad with computational thinking so not to overwhelm the students. Getting them to see that a computer performs things in steps just like our writing will be a great cross between language arts skills and computer programing skills" (PST1, T1). All pre-service

teachers were able to continue using CT vocabulary or provide a relevant explanation about CT in their concept mapping lessons (T2). However, about half of the pre-service teachers did not particularly address CT in their final lessons (T3).

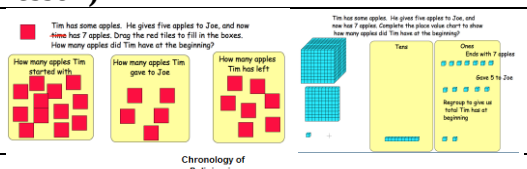
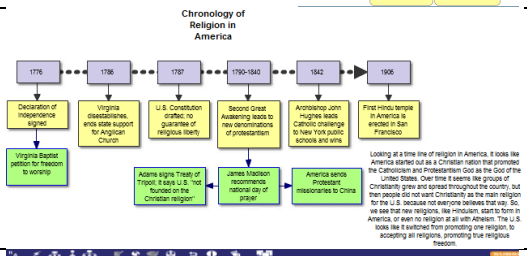
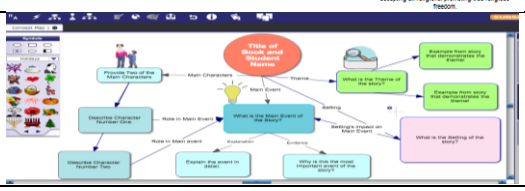
Table 4.14 CT Competencies of the High Start Group.

CT Competencies	**T1_Programming Lesson Plan**	**T2_Concept Mapping Lesson Plan**	**T3_Case Report**
Addressing CT Concepts	67%	100%	55%
Viewing CT as Problem Solving Skills	22%	-	-
Not Mentioned/ Not Related/ Unclear	10%	-	44%

Attitude and knowledge related to computing technologies (TK-CT). Most pre-service teachers from the High Start Group did not previously interact with computing tools such as Scratch. However, they reported enjoying their learning experience related to programming. Moreover, 90% of the pre-service teachers were very positive about integrating programming within their classrooms, although 10% had some hesitation. The pre-service teachers, overall, were able to acquire fundamental knowledge related to Scratch and subsequently integrate programming into designing meaningful lessons (T1). For instance, the pre-service teachers were able to adopt pedagogical approaches for guiding students to become acquainted with programming in Scratch, such as modeling when creating a coding program with the students or collaborating with the school technology teacher for guiding students through the completion of the coding projects. Additionally, all pre-service teachers appeared to be comfortable in utilizing the concept

mapping tools and created concept mapping examples (Table 4.15) in their lesson plans (T2). By having meaningful understandings of computing technologies, the pre-service teachers from the High Start Group were able to provide adequate evaluations about what specific technological background their students should acquire in order to complete the lesson activities.

Table 4.15 Concept Mapping Examples of the High Start Group.

PST ID	**Subject Area**	**Concept Map Example (100% of the PSTs of the Low Start Group created a concept map for their lesson)**	**Supported CT Practice (Defined based on the Learning Goals and Lesson Activities)**
1	Math		Simulation
20	Social Studies		Algorithmic Thinking
56	Literacy		Abstraction

However, even among the pre-service teachers who were placed in a technology-rich environment, some did not design and implement lessons related to CT. Table 4.16 below shows that some pre-service teachers used Kahoot in designing CT-infused lesson. For instance, one pre-service teacher (PST 31) used Kahoot as the post-assessment in her classroom and thought her lesson supported CT because students were problem solving

questions. This reflects that the pre-service teachers in this group encountered some difficulties in selecting computing tools to promote CT-infused lesson when implementing CT in authentic learning contexts.

Table 4.16 Selected Technologies for Final Case Reports of the High Start Group.

Technology	**T3_Case Report**
Interactive Whiteboard	22%
Google Classroom	11%
Kahoot	33%
Internet for Research	11%
Concept Map	11%
Hour of Code	11%

CT implementation with contextual factors (TPACK-CT & Context).

Importantly, as shown in the quantitative result, the increasing TPACK-CT trend did not continue, and significantly diminished at T3. In fact, from the case reports among the High Start Group, pre-service teachers' decisions about designing lessons for teaching in an authentic settings were often influenced by many contextual factors. These factors included lesson objectives, students' background (e.g., content readiness and technology background) and available technologies. For the pre-service teachers who used the assessment tool (Kahoot) for their final cases, they all taught this lesson for a relatively larger student group. With the consideration of available technologies and the content objectives, they selected to use Kahoot to assess students' content understandings through an engaging way. Moreover, access to working technology was also a factor that influenced pre-service teachers' decisions in implementing CT lessons. For instance, one pre-service teacher (PST 20) reported that his classroom had to wait for several weeks to use the Smartboard until it got fixed. Another pre-service teacher reported that the laptops

which were planned to use in her lesson did not charge appropriately, which led to several student behavior issues related to sharing laptops in the lessons. Therefore, as shown in Table 4.17, more than 50% of the lessons did not use technology for integrating CT in the pre-service teachers' case reports (T3).

Table 4.17 Purposes of Integrating Technologies for Final Cases of the High Start Group.

Using Technology for	T3_Case Report
Supporting CT and Content Understandings	44%
Engaging Learning	22%
Assessing Learners' Knowledge	33%

High Start Group Representative Cases. This section describes two representative cases of the High Start TPACK-CT trajectory group following the same format as the Low Start Group.

Kate's case. Kate majored in Elementary Education with a concentration in Middle School Math Education. During her participation in the redesigned educational technology course, she had her field placement at a 5th-grade classroom in a rural school. Kate's classroom had 16 Chromebooks, 3 student desktops, a Smartboard and an Elmo document camera. There was no computer lab at her school. Although Kate worked with 5th graders, her CT-infused lesson plans were not merely designed for students at this grade level. She demonstrated knowledge and skills related to CT integration at various grade levels and subject areas.

Kate planned a week-long unit to integrate programming into a 7th-grade math unit. Her lessons aimed to scaffold students' work in groups to create probability games

(TPACK-CT). In her second lesson plan, Kate harnessed an online concept mapping tool for students to organize and represent information collected from a research assignment related to a social studies topic (TPACK-CT). In her case report, Kate collaborated with another student teacher to create a Smartboard activity for a 5th-grade science lesson. The Smartboard activity, specifically, was for students to organize and represent results from science experiments (TPACK-CT).

Kate entered her student teaching phase after the completion of the course. In her first student teaching semester, Kate taught 8th-grade math in a rural school. The school population was primarily Caucasian. Her classroom had various types of technology, including a Smartboard, an Elmo document camera and a set of Chromebooks. In her second student teaching semester, Kate student taught in a 5th-grade classroom in a suburban school. The school population consisted primarily of Hispanic and Asian students. The classroom was equipped with a Smartboard, an Elmo document camera and a collection of iPads. However, Kate's class did not necessarily use the interactive features of the Smartboard. They used the Elmo document camera every day.

Kate did not receive additional training related to CT integration besides the course, however, she was able to provide several CT-infused lesson examples in conjunction with her student teaching experience. Reflecting on her teaching experience, Kate reported that the demanding curriculum hindered her decisions in implementing CT into the curriculum through technology integration. Kate proposed to redesign an 8th-grade math lesson focusing on graphing equations using two particular educational applications in her classroom. This redesigned lesson allowed students to have full

exploration and interaction with technology. As Kate explained, the technology integration of the lesson aimed to promote students' understandings of math concepts and CT (e.g., simulation and parallelization).

Amber's case. Amber majored in Elementary Education with a concentration in English as a Second Language. During her participation in the redesigned educational technology course, she had her field placement at a 2nd-grade classroom in a rural school. The school had 25 Chromebooks, but no policy was found for signing them out for classroom use. Amber's classroom was equipped with three MacBook computers, one Smartboard and an Elmo document camera. A computer lab was equipped with 25 MacBook computers and opened for all students during their media center special once a week. Amber's lesson plans reflected her knowledge and skill related to designing CT-infused lesson for various subject areas and grade levels.

Amber embedded programming in a 4th-grade social studies lesson. In particular, students utilized Scratch to program a story representing a historical event (TPACK-CT). Her concept mapping lesson was designed for 2nd graders to create a representation of the water cycle (TPACK-CT). In her case report, Amber merged the concept mapping lesson into a week-long science unit (TPACK-CT). The concept mapping component, however, had to be modified to become a whole group activity based on several factors, such as availability of technology and students' technological background at her field placement.

Amber entered her student teaching phase after the completion of the course. In her first student teaching semester, Amber worked in a 4th-grade classroom at an urban charter school. The school population consisted of Caucasian (55%), African American

(25%), Hispanic (10%) and Asian (10%). The school, however, did not have a lot of technology. In her second student teaching semester, Amber taught 4th-grade literacy at an urban public school. The dominant student population was Hispanic (65%) with African American (22%) and Caucasian (13%). Nearly half of the students were English Language Learners. Chromebooks and a Smartboard were available in her classroom. Additionally, students had a technology class where they had personal computers.

Similar to Kate, Amber did not receive additional training about CT integration. Overall, she was able to provide a linkage between CT integration with her teaching practices. Amber, however, encountered some challenges (e.g., lack of working technology) in implementing CT into her classroom. When addressing these constraints, she envisioned planning to infuse CT into a science lesson. This lesson integrated technologies for students to track and represent data after conducting scientific experiments (TPACK-CT).

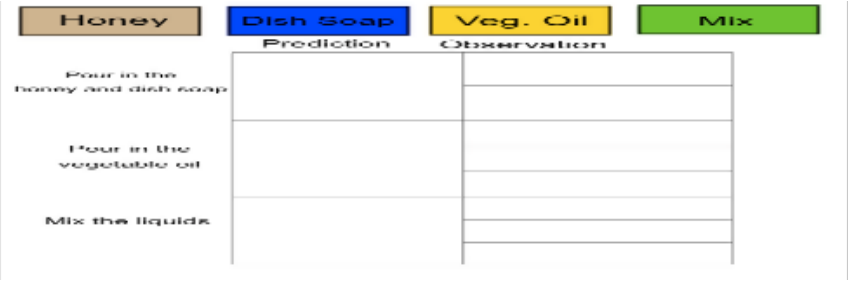
Technological, pedagogical and content representations in CT implementation (TPACK-CT). Kate and Amber started with high TPACK-CT scores in their programming lessons. In fact, Kate and Amber provided sound explanations around the ways in which their technology-integrated lesson plans can support the development of students' CT knowledge and skills. For instance, Kate's week-long lesson plan provided an example of how to incorporate programming technology into a specific content area. The main learning activity of her lesson was to have students work in small groups to create a probability game using content and programming knowledge. In order to achieve this goal, Kate mapped out various pedagogical strategies for a week-long lesson unit to

guide students to obtain content and programming knowledge and create programming projects (TPACK-CT). Likewise, Amber's programming lesson plan reflected her careful consideration of content, pedagogy, technology and CT aspects (TACPK-CT). In Amber's programming lesson (T1), she utilized various pedagogical approaches to help students gain content and programming knowledge. She first had students conduct research about their projects related to the lesson objective. Subsequently, she planned a detailed introduction of Scratch to the class. Moreover, she integrated a programming tool for students to work in small groups to create a story representing the chronological stages of a historical event that they were studying (TPACK-CT).

Kate and Amber continued to demonstrate high TPACK-CT as they designed concept mapping lessons (T2). Kate used concept mapping in her social studies lesson through two main learning activities planned with pedagogical considerations (TPACK-CT). First, students conducted research about their ancestors to gain a general experience about their family history. After three days of research, they would then use an electronic concept mapping tool to organize and present their research findings (TK-CT). Amber designed a concept mapping lesson in a 2nd-grade science lesson (TPACK-CT). After students received whole group instruction about the water cycle through reading and observing the teacher's demonstration of the water cycle by using concept mapping tools (TK-CT), Amber had them work as groups with Chromebooks to create a representation of the water cycle.

In their final lessons, Kate and Amber continued to maintain relatively high TPACK-CT. In particular, their lessons were designed based on their sophisticated

considerations about their teaching contexts. Kate integrated a Smartboard into a 5th-grade science lesson about the density of different liquids (TPACK-CT). For this specific lesson, Kate and another student teacher used the clone feature of the Smartboard to produce multiple copies of the same labels (Figure 4.19, top). The purpose of doing so was to allow students to move, sort and organize the labels to make predictions in different conditions. After the students saw the teachers' demonstration about mixing the liquids, they recorded their observation in the right column. The whole class then compared and contrasted their predictions and observations. Similarly, Amber and her teaching partner taught a science lesson on the water cycle using available technologies in her 2nd-grade classroom. In particular, she had students complete the concept map on the interactive whiteboard by "dragging the labels on the smartboard to complete a concept map" (Figure 4.19, bottom).



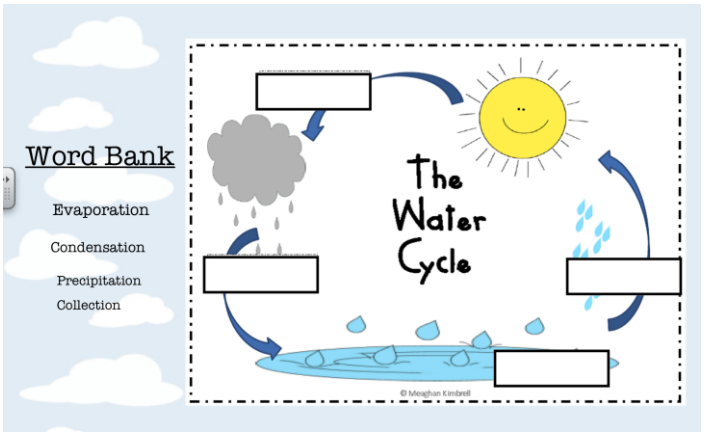


Figure 4.19 Final Case Products of Kate (Top) and Amber (Bottom).

CT competencies (CT). The cases of Kate and Amber reflected that they obtained accurate and moderate CT understandings. Moreover, they did not simply report how CT was supported in their lesson, they provided a detailed explanation about how CT was embedded to support students' content understanding. For instance, as Amber articulated how her lesson supported students' CT, she said: "I believe that having students work on this concept through programming will allow them to build on their knowledge of sequencing and attention to detail. These concepts will be important not only in the content knowledge of history but will be crucial when they are programming their story". Kate reported that her concept mapping lesson (T2) addressed the CT concepts related to data. Their final cases also reflected that they were able to integrate CT concepts into their lessons (T3). Amber, however, did not specially address how her final lesson supported students' CT but thought having students individually create concept maps would promote their CT "that develops alongside the use of technology".

From the interviews, Kate and Amber discussed individual CT concepts listed on the review sheet. They also grounded their responses in the context of their teaching

experience: “I definitely think we do a lot [of] problem decomposition and algorithmic thinking. Just in the context of math, …I think having a precise sequence of stuff that they use to solve a problem is something they relate to” (Amber, T4). Amber and Kate, however, appeared to be unfamiliar with some CT concepts such as data and parallelization at the beginning of the interview. Therefore, they were uncertain about applying these CT concepts into their classrooms, considering students’ grade levels and knowledge. As Kate reported, data was a more difficult skillset for younger students as they “struggled with viewing and reviewing the data” (Kate, T4). Likewise, Amber was “not sure” about the definition and the application of parallelization and simulation. However, when they were encouraged to explain their thoughts related to such concepts, they seemed to become more comfortable in talking about the CT concepts once they started to mimic one CT concept based on its definition on the review sheet. The excerpt below illustrates how Amber explained her thoughts related to her unfamiliar CT concepts:

> Q: Do you have other things to add into your answers, such as data collection, automation, parallelization?
> A: I am not sure about parallelization. I know we did talk about I think this kind of idea. Sometimes I have them do group work; we give everyone a role. Instead of just looking at the thing and have one person write it and anyone else just hanging out, we do “ok you are going to be the recorder, you are going to be the measurer”. Like specializing each person or a specific task really helps them be effective at something they would do on their own.
> Q: That’s excellent.
> A: Yes! And I never use that word (parallelization) to talk about it that way. I would say “simulation” when I'm talking all these. Just representing a process is all they can display to work a problem. They did do some science experiments. (However) By the time I got there they did less science and more social studies where they were analyzing data.

Moreover, with a developing understanding related to some of the uncertain CT concepts, Amber and Kate became comfortable in applying such concepts when envisioning implementing CT-infused lessons in their future classrooms. Kate elaborated that her 8th-grade math lesson could be redesigned to promote students' CT in data and simulation. Amber articulated that her science lesson was designed to engage students to conduct scientific experiments and her lessons support students' CT on data, parallelization and simulation.

Therefore, the cases of Kate and Amber represented solid CT competencies. They were proficient in describing, reflecting and applying various CT concepts into teaching practices including simulation and parallelization.

Attitude and knowledge related to computing technologies (TK-CT). With an adequate understanding of the Scratch software, Kate and Amber recognized the needs of merging programming into their lesson, such as equipping students with the coding knowledge in order to complete coding products for the lessons. Consequently, each of their programming lessons addressed a component to facilitate students to become familiar with using Scratch. For instance, coming from having no coding background, Kate became comfortable with using Scratch and "it (the learning experience) made me feel that I could actually create a computer program!" Her programming lesson plan involved a series of learning activities to support students' content and coding development. Kate firstly selected a probability game that had already been created on Scratch and had students play this game to compute both theoretical and experimental probabilities. On the next day, she introduced how to program on Scratch and allowed

students to explore different programming features. The following two days were for students to work in groups to create their own probability games and share them with other groups. The last day of the lesson was to have students share their game and compute theoretical and experimental probabilities by playing their games.

Likewise, Amber's programming lesson reflected that she had a solid understanding about the Scratch software, and she was able to employ various approaches to help students gain knowledge related to programming on Scratch (T1). She introduced a CS Unplugged activity "Harrold the Robot" to students before introducing programming. The purpose of doing the CS Unplugged activity was twofold: a) to "clarify the level of detailed instructions that the computer needs in order to complete a task", and b) to "allow students to understand that they have to break up their commands into a specific order in creating their story project". Amber then modeled how to navigate Scratch and showed some storytelling Scratch projects as examples for students to get familiar with the programming features. Students then worked in small groups to create a Scratch story representing the chronological stages of a historical event related to the content.

Kate and Amber continued to demonstrate a solid understanding related to the computing tool at T2. For Kate's lesson, she had students use the Internet for research and organize their research findings using the concept mapping tool. The left image in Figure 4.20 presents her own example created for the lesson. Amber's lesson integrated the concept mapping tool for students to create a representation of the water cycle, utilizing various pedagogical approaches to facilitate 2nd-grade students obtain sufficient

knowledge before they were asked to create the representation with the concept mapping tool. She also provided a concept mapping example for her lesson (Figure 4.20, right).

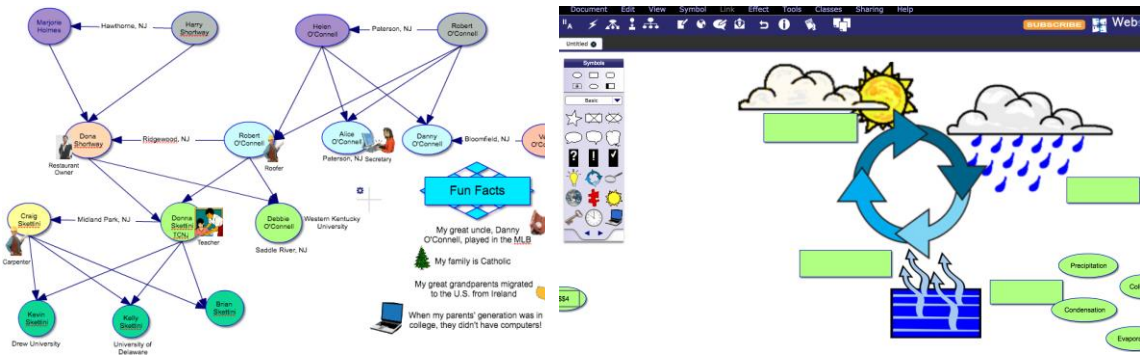


Figure 4.20 The Concept Mapping Examples by Kate (Left) and Amber (Right).

In their final lesson, Kate and Amber were able to tailor a CT-infused lesson based on the available technologies in their classroom. Kate worked with another student teacher to explore and create a Smartboard activity which allowed students to manipulate data. Amber used a document camera and the Smartboard for her lesson, however, Amber precisely pointed out that "the main technology integration was in the use of the concept map activity".

In their interviews, Kate and Amber talked about how the technologies listed on the review sheet could be used for implementing CT. Simultaneously, they also reported that the technologies (e.g., Chromebook, Smartboard) which were currently used in their classroom were not used to support CT. This situation could be explained by several factors related to their specific teaching contexts regardless of their technological knowledge in relation to CT.

CT implementation with contextual factors (TPACK-CT & Context). The cases of Kate and Amber, especially their final case reports and interviews, indicated that several

contextual factors influenced their decisions and development related to CT implementation in authentic classrooms.

Students' technological background and behavioral issues related to using technologies were key factors that needed to be considered during lesson planning. For instance, Kate's lesson (T3) was developed based on her previous observation in her classroom. As she observed, the classroom teacher used a smartboard on various occasions and her students were very comfortable in using this technology, therefore, Kate designed and implemented a CT-infused lesson using the Smartboard in her classroom. Similarly, although Amber's concept mapping lesson was designed for students to create online concept map projects in small groups, she had to justify this learning activity since she had never seen her 2nd graders use computers in her field placement and she assumed her students were not proficient in "pulling up the concept map on their computers" (Amber, T3). Therefore, she had her 2nd grade students complete the concept map on the interactive whiteboard by "dragging the labels on the smartboard to complete a concept map", instead of creating their own concept mapping project. However, her lesson could only have 4-5 out of 23 students come to interact with the Smartboard. Additionally, her class had 2-3 students who required additional behavioral management support and the whole class was very chatty. As Amber reflected, she would collaborate with the school computer teachers to have students develop technological skill and she would use more technologies in the classroom to have students use technology on their own.

Having access to available and working technologies became one of the factors to influence the pre-service teachers' TPACK-CT decisions in planning lessons for classrooms. In fact, Amber talked about this constraint which prevented her decisions in CT implementation. She struggled to connect how CT could be implemented through technology such as a Smartboard because her current classroom did not have working technology:

> "The whiteboard got used some but honestly, it's been broken for a couple of weeks now. It's really hard at the end of the year. I had been putting a ticket for a while back but it's been pretty much just a project for a little bit. My school district doesn't have a full time IT person. So whenever the person comes to the school, he has 50 tickets… But still having the projector is good. We are doing fractions. So having them able to see that and not worry about my drawing. It's definitely beneficial." (Amber, T4).

Moreover, the school curriculum and instructional schedules were another factor influencing the degree of CT implementation. In fact, the schools where Kate and Amber student taught at did not acknowledge the role of CT in their curriculum and instructional agenda. Therefore, as Kate said: "Just being in a student teaching placement, you are confined to what your clinical educator normally does. It is hard to implement newer or maybe less tried out lessons." Moreover, although Amber was interested in integrating CT into science, her school did not recognize the importance of science and social studies: "The teachers are really focused on getting students ready for ELA and math testing. We haven't even done social studies for so long just because they just have a hard time for testing, testing, testing. There are strong requirements for the district to be doing that all the time" (Amber, T4). Additionally, although Kate had used two educational applications that "gave students opportunity to have to think about how to manipulate

different figures and things that help them to develop CT skills", she "never had them do it themselves" (Kate, T4). In fact, Kate's school had very demanding curricula especially for math and she thought this might be a reason to hinder CT implementation using technology in schools:

> "I think the curriculum is a big part of it. Like I said that I don't feel we really use technology as well as we should have. You are given exactly what you need to do every day even though it doesn't involve technology, or it doesn't effectively involve technology, then you are limited about what you can do. I think that is the big factor. I am also thinking just finding effective ways to use it [technology into instruction]. A lot of teachers will have students look something up on their iPads and say they are using technology. They are using the technology, but they are not using it in the way that's going to develop their CT skills. They are going to help students really use technology in the way that could benefit them more than just looking something up on their iPads or chrome books" (Kate, T4).

Chapter Summary

Phase I of the study revealed that the redesigned educational technology promoted pre-service teachers' CT understanding, both in concepts and implementation. In addition, results of the Phase I study showed that the majority of the pre-service teachers did not hold positive attitudes towards CT comfort, interest and career choice. Additionally, Phase I results revealed that the role of computing tools was conceptualized differently among participants. Results of Phase II showed that the pre-service teachers demonstrated uneven enactments of CT integration at first, which resulted in three trajectories. However, pre-service teachers' lesson plans reflected similar pattern about the mean score of TPACK-CT regardless of their starting points. There were three factors that led to pre-service teachers' TPACK-CT representation of these trajectories. These factors included CT competencies, attitudes and knowledge related to computing technologies and contextual considerations.

In summary, pre-service teachers' understandings of CT concepts were significantly improved at the end of the redesigned educational technology course from the quantitative results of the survey data. Specifically, pre-service teachers were able to obtain knowledge related to CT such as using CT vocabularies or providing an accurate and detailed explanations in relation to CT. Moreover, participants had established knowledge and skills to implement CT into classrooms through integrating computing technologies. Although participants had demonstrated improvements such as in the construct of CT definition during the course participation, their TPACK-CT trajectory reflected by their lesson plans did not show a linear trend, in fact, their TPACK-CT enactments were influenced by different factors, such as their knowledge about CT and computing technology situated in a specific context. An extensive discussion related to the results is presented in the next chapter.

Chapter 5

DISCUSSION

Study Synopsis

Computational Thinking (CT) has been recognized as a fundamental analytical thinking skill required for all students to navigate the digital world (CCSS, 2010; NGSS, 2010; Wing, 2006). Therefore, it is necessary to promote CT into K-12 settings in order to equip students with a CT-related skillset (ISTE, 2016). One way to implement CT in classrooms is by investing in teacher development, especially teachers' knowledge in relation to designing CT-infused lessons (Barr & Stephenson, 2011; Mouza et al., 2017b). This work addresses a strategic starting point to prepare future teachers with the knowledge and skills needed to infuse CT in K-12 curricula. In particular, this work is situated in an educational technology course offered through a four-year teacher education program in the United States. This course was tailored to provide various active learning activities for equipping pre-service teachers with the knowledge and skills to weave CT into classroom settings. The course was grounded in the TPACK framework, with an emphasis on CT concepts, computing technologies, and CT-related practices (TPACK-CT). Specifically, this course introduced computing tools available for pre-service teachers to use in the classroom. Importantly, the course provided opportunities for pre-service teachers to connect their content and pedagogical decisions

with the selection of appropriate technology as they designed CT-infused lessons. Accordingly, this work aimed to examine how pre-service teachers develop an understanding of CT knowledge, including its application to school curricula and everyday pedagogical activities (TPACK-CT).

For the purpose of this work, I planned a two-phase mixed-methods investigation to gather progressive and precise understandings of pre-service teachers' development related to CT implementation. Phase I focused on exploring how pre-service teachers developed CT related knowledge and practices with technology integration throughout their participation in the redesigned educational technology course. For this purpose, I adopted a mixed-methods concurrent design and collected pre-service teachers' responses to a pre- and post-CT questionnaire. This questionnaire contained 26 Likert-scale survey items and three open-ended questions related to integrating computing technologies. A total of 135 pre-service teachers from three consecutive semesters participated in the Phase I study through completing the pre- and post-CT questionnaires. Quantitative data collected from the 26 Likert-scale items were analyzed using a paired t-test, while qualitative data collected from three open-ended questions were analyzed using the constant comparative method.

Grounded in findings from Phase I, the Phase II study aimed to understand the representation of pre-service teachers' TPACK-CT practices. The Phase II study explored and exemplified pre-service teachers' CT trajectories throughout their participation in the redesigned educational technology course using a subset of participants. Additionally, the Phase II study continued to focus on bridging the connection between pre-service

teachers' CT ideas, use of CT tools and CT practices that relate within a knowledge system that encompasses content, pedagogy and technology. For the purpose of the Phase II study, I employed a mixed-methods explanatory case study design, in which I used quantitative data to inform my selection of the case participations. Data for Phase II work included 171 lesson plans which pre-service teachers created throughout the course at three sequential points of time. Furthermore, I recruited six pre-service teachers of this smaller sample for a follow-up interview to examine whether they implemented any CT practices in their classrooms. Quantitative data collected from scoring 171 lesson plans of 57 pre-service teachers were analyzed using repeated measures ANOVA, while qualitative data collected from multiple sources, including pre-service teachers' lesson plans and interviews, was analyzed using a strategic approach consisting of within and cross-case analyses.

Results from this work revealed four primary themes. First, pre-service teachers developed CT understandings after participating in the redesigned educational technology course. This was reflected by the significant t-test results related to the CT definition construct. Moreover, qualitative results showed that pre-service teachers were able to obtain a general understanding related to CT. However, the breadth and depth related to their CT understandings varied in different lesson plan design settings. Secondly, pre-service teachers demonstrated uneven knowledge related to using and integrating certain computing technologies into lesson design. Thirdly, despite pre-service teachers starting at different TPACK-CT scores, their TPACK-CT trajectory was non-linear across three tasks which followed a sequential order. Compared with their initial TPACK-CT scores

at the programming lessons, most of the pre-service teachers had higher scores at their concept mapping lessons. However, a significant reduction was found in most of the pre-service teachers' final lessons, in which pre-service teachers implemented a CT-infused lesson in their field placement classrooms. Most frequently, pre-service teachers in this study were facing several contextual factors which affected their decisions in the design and implementation of CT-infused lessons in the classroom settings.

Discussion of the Main Research Findings

Teacher learning in relation to CT in the context of technology integration.

Engaging pre-service teachers from various disciplinary areas besides computer science to precisely grasp the definition of CT and implement CT into their teaching practice would be challenging (Croff, 2017; Yadav et al., 2017). Results of the study reflected that not all pre-service teachers knew about CT before enrolling in the redesigned educational technology course, however, they were able to design and implement CT-infused lesson at one or more time points throughout the course. The main findings of the study revealed that pre-service teachers' CT capabilities were malleable regardless of their previous enactment with CT (Bower et al., 2017; Mouza et al., 2017b; Yadav et al., 2016).

The design of this course targeted key design principles to provide pre-service teachers with the knowledge of CT and computing technologies based on the practical TPACK modules by Harris and Hofer (2009). Specifically, pre-service teachers in this course were scaffolded to design CT-infused lessons with their content and pedagogical decisions using learned computing technologies. Results of the study reflected that equipping pre-service teachers with CT-related knowledge, computing tools, and CT-

related practices could positively promote pre-service teachers to gauge CT ideas and implement CT-related practices. Moreover, pre-service teachers who had no prior knowledge related to CT gradually developed CT competencies through exploring computing technologies and demonstrated growth in embedding CT with their content areas through using technologies. Noticeably, several key design components targeted by this redesigning educational technology might be the reasons contributing to this success.

First, introducing CT definitions, practices and vocabularies is fundamental for preparing pre-service teachers to develop CT competencies (Yadav et al., 2004). The main results of the study have shown that some pre-service teachers without having programming experience were able to use CT vocabularies or to provide an explanation related to CT practices in their programming lesson plans. This group of pre-service teachers grew in the concept mapping during the middle of the course.

Secondly, as the theoretical framework of the study, the TPACK framework emphasized the role of technological knowledge (TK) in the contribution of teachers' overall TPACK representation. In fact, among the knowledge base (technological knowledge, content knowledge, and pedagogical knowledge), TK had a direct positive influence on TPACK; therefore, teachers with more proficiency related to technology were more likely to have high self-efficacy in integrating technology (Koh et al., 2011). Similarly, the course described in this work focused on equipping pre-service teachers with knowledge of computing tools which was crucial to fostering pre-service teachers' implementation of CT in their practices (Angeli et al., 2017; Bower et al., 2017; Jona et al., 2014). Moreover, most of the tools (e.g., concept mapping tool, Smartboard)

introduced in the course are easily accessible to the pre-service teachers in authentic classrooms, which in turn helped pre-service teachers connect and transfer their learning into classroom settings (Kumar & Vigil, 2011).

Finally, the course aimed to help pre-service teachers understand the application of computing technologies through lesson plan design (Tondeur et al., 2011). Therefore, implementing CT with technology into K-8 settings was viewed as applicable by the participating pre-service teachers. In particular, participants provided in-depth strategies and thoughts regarding CT implementation. Some of the participants offered analytic perspectives about how to implement CT in classroom settings. For instance, they envisioned combining the use of computing tools with specific content and pedagogical decisions; this evidence significantly distinguished and expanded from their prior understanding of CT implementation.

The short-term effect of the course was reflected by pre-service teachers developing knowledge and skills in designing CT-infused lessons. An increasing percentage of the pre-service teachers were able to develop a hypothetical CT lesson, while a small group of pre-service teachers could even design and integrate CT into an authentic classroom setting. Most importantly, although the pre-service teachers demonstrated various levels of TPACK-CT at their programming lessons, their TPACK-CT development continued to grow in the concept mapping lessons. At this time point, the gap between the three different groups was bridged. This finding could be potentially explained by two reasons. The first reason related to the course design which the key design components described above positively contributed to pre-service teachers' CT

implementation. For example, engaging pre-service teachers into lesson planning design activities enhanced their understandings of CT concepts and implementation (e.g. Stephenson et al., 2005). The second reason related to the nature of the concept mapping technology. As most of the pre-service teachers reported, creating a complete and working project using programming tools (e.g., Scratch) were challenging, especially for the ones who had no to limited prior knowledge. The concept mapping tools, however, were easier for pre-service teachers to approach and navigate, which resulted to help pre-service teachers develop stronger CT understandings and implementation. The pre-service teachers' final lesson plans, overall, did not present a solid TPACK-CT demonstration. However, this did not truly reflect the course effects. In fact, the contextual factors which evolved in the classroom settings influenced teachers' instructional decisions and effects with the use of technologies (e.g., Jaipal-Jamani & Angeli, 2017). The long-term impact of the course could not be precisely evaluated by the study due to the small number of interviewees, however, the interview data revealed that pre-service teachers were able to recall CT knowledge and certain types of computing tools. More importantly, several pre-service teachers were able to envision how CT could be implemented in their future classrooms after a review sheet was provided. Therefore, redesigning the educational technology coursework for pre-service teachers could be a promising approach to introducing pre-service teachers to CT (Jona et al., 2014; Yadav et la., 2017).

The relationships between contextual factors and pre-service teachers' CT implementation. The study results showed that when the pre-service teachers designed

hypothetical CT lesson plans, their CT competencies, attitude, and knowledge were found to be more salient in their planning of CT-infused lessons. For the pre-service teachers who obtained relatively solid understandings towards CT concepts and computing tools, they were able to design lessons that demonstrated strong TPACK-CT, such as the programming lesson designed by Amber. However, for the pre-service teachers who obtained limited understandings towards CT concepts and computing tools, they struggled to provide lesson plans which cohesively connected pedagogical, content knowledge into CT integration. For instance, Sophie's lesson reflected her limited understandings of the programming tool Scratch since it was used as a game for students to practice math questions.

As shown in the study results, pre-service teachers encountered difficulties in integrating CT in the classrooms. This result was not surprising since teaching in the classrooms is a complex process which requires teachers to consider a range of personal (e.g., value) and contextual (e.g., resources) factors (Goos, 2005; Kennedy, 2005). When pre-service teachers designed and implemented CT in the classrooms, they needed to fit their lesson plan design within the specific teaching context, such as learners' background, available technologies and so forth. Therefore, pre-service teachers often needed to make more decisions in weaving technology, content and pedagogy into their lesson design. In the example of Lily's final lesson plan, she noticed that the interactive whiteboard was the often-used technology in the classroom, therefore, she designed a Smartboard activity for her students to sort items (analyzing and organizing data) related to a social study topic. However, most pre-service teachers did not successfully integrate

CT into the classrooms. It is worth noticing that the final case report was the only assignment which required the pre-service teachers to implement CT in the classrooms. Therefore, as novice teachers, the pre-service teachers lacked the experience and knowledge in teaching in authentic classrooms.

When the six pre-service teachers were interviewed one year after they completed the course, no evidence was found that they had purposefully integrated CT in their year-long student teaching practices. All pre-service teachers needed to rely on the review sheets to recall specific CT practices. Connecting the interview data with all pre-service teachers' lesson plan data, their CT enactment in the classroom was influenced by factors from three contextual scopes: macro, meso and micro (Porras-Hernández & Salinas-Amescua, 2013). Connecting the definitions provided by Porras-Hernández and Salinas-Amescua (2013) with the study results, the macro level can be defined as national or global initiatives related to computing expectations driven by economic, technological, social and political states (e.g., CS for All, Makerspace Movement). The meso level can be defined as organizational efforts influenced by culture and values within a specific community (e.g., district or school instructional priority). Finally, the micro level can be defined as the classroom context developed with resources and procedures (e.g., available technological resources).

In fact, the study results showed that the three contextual scopes affected pre-service teachers' enactment and development of TPACK-CT differently. Current initiatives had been put forth to emphasize the importance of CT, such as placing CT into the educational standards, including the Common Core State Standards, but CT was not

yet fully embedded in K-12 settings (macro level). As reported by the six interviewed pre-service teachers, CT was not a priority in the schools they were placed (meso level). Therefore, the interviewed pre-service teachers reported that CT was not mentioned in their placements and their mentor/classroom teachers did not address CT in their instruction due to demanding curricula. Since the pre-service teachers did not continue their TPACK-CT journey after they left the course, they tended to provide explanations about how to use technologies to promote general learning which were aligned with what they had been experiencing in the classroom, regardless of the effectiveness of these technologies. Besides, pre-service teachers reported that lacking access to technology and lacking expert support were key reasons hindering their decisions around CT implementation (micro).

Describing a knowledge paradigm for CT implementation in authentic teaching environments. The main results of the study showed three non-linear trajectories of pre-service teachers' enactment of CT implementation. Additionally, the study results revealed that pre-service teachers' successful integration of CT in school curricula relied on several factors such as their CT competencies. The results suggested that pre-service teachers in this study demonstrated different knowledge in planning a CT lesson in the context of technology. Therefore, I illustrated a knowledge paradigm to present pre-service teachers' knowledge domains related to their CT-integrated lessons designed throughout the redesigned educational technology course. This knowledge paradigm is a variant of the Pedagogical Content Knowledge framework (Shulman, 1987) and the TPACK framework (Misha & Koehler, 2006) and shares similarities with these

two frameworks. However, the knowledge paradigm was employed to reflect the differences and similarities among three trajectory groups, connecting the qualitative and quantitative results. In particular, this knowledge paradigm presents four types of knowledge needed for CT integration, resulting from the Phase II qualitative results. The four types of knowledge were: CT knowledge, technological knowledge, content and pedagogical knowledge. In Figure 5.1 (left) presented below, the four types of knowledge were placed in four quadrants in one coordinate plane. Furthermore, these types of knowledge are placed within the context where they function. Data collected from the pre-service teachers in this study reflected that these four types of knowledge and contextual considerations often intertwined with each other (Figure 5.1, right). The interactions of the knowledge domains within this knowledge paradigm are iterative and dynamic, weighting differently for specific individuals and contexts (Angeli et al., 2017).

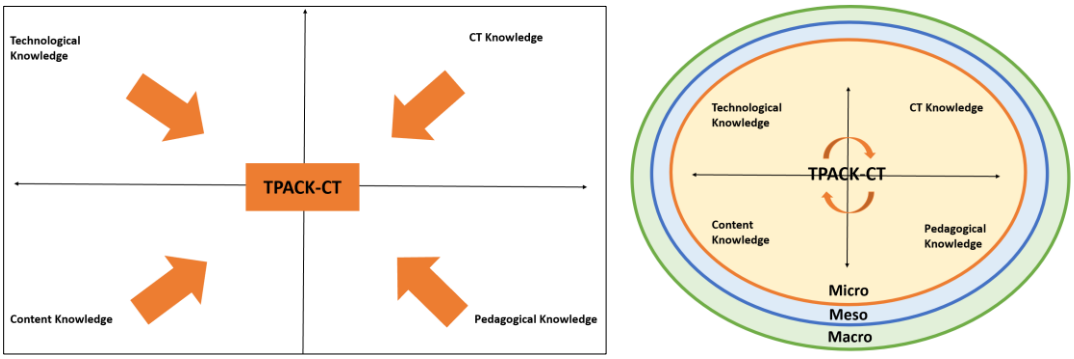


Figure 5.1 A Knowledge Paradigm Related to CT Implementation in Classrooms.

To better illustrate how this knowledge paradigm represented the essential knowledge types needed for CT integration, I described the differences and similarities

among three TPACK-CT trajectory groups. Especially, I used the six representative cases in conjunction with their respective TPACK-CT scores at each time point.

Three TPACK-CT trajectories started apart at T1 (the highlighted area in Figure 5.2), when the pre-service teachers integrated programming into lesson plan designs. More specifically, lesson plans of the High Start Group (e.g., cases of Amber and Kate) reflected that highly-scored TPACK-CT programming lessons addressed the four knowledge components (see Figure 5.1 left). Cases of the Medium Start Group showed that pre-service teachers started to combine the knowledge of CT, technology and content into lesson planning consideration; however, their pedagogical knowledge did not weave into their lesson plan design process. Finally, cases of the Low Start Group mainly addressed their knowledge of content and pedagogy into the lesson design, but this was not connected to CT.

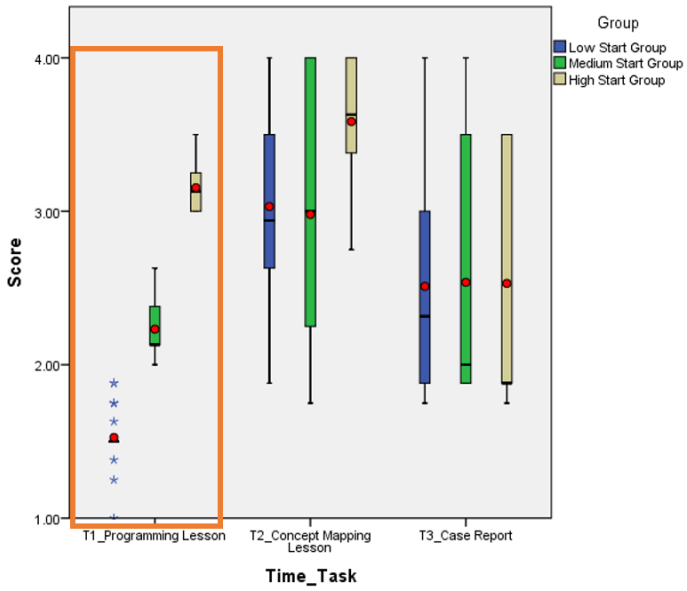


Figure 5.2 Boxplots of TPACK-CT Scores Related to Designing CT Lesson with Programming Tools among Three Trajectory Groups.

Despite having stratified TPACK-CT starting points, each trajectory group showed a higher mean score of TPACK-CT in integrating CT using concept mapping tools (Figure 5.3). Moreover, the quantitative results showed that no difference existed among the three clustered groups in the concept mapping lessons. In fact, lessons of the representative cases reflected their synthesized knowledge, based on the four types of knowledge. For instance, Sophie's concept mapping lesson demonstrated her improved knowledge and decisions in designing TPACK-CT lessons compared to her programming lesson, which did not relate to CT integration. Sophie's concept mapping lesson elaborated how the concept mapping tool (technological knowledge) was integrated to facilitate the whole group discussion (pedagogical knowledge) on decomposing (CT knowledge), the math concept of subtraction (content knowledge).

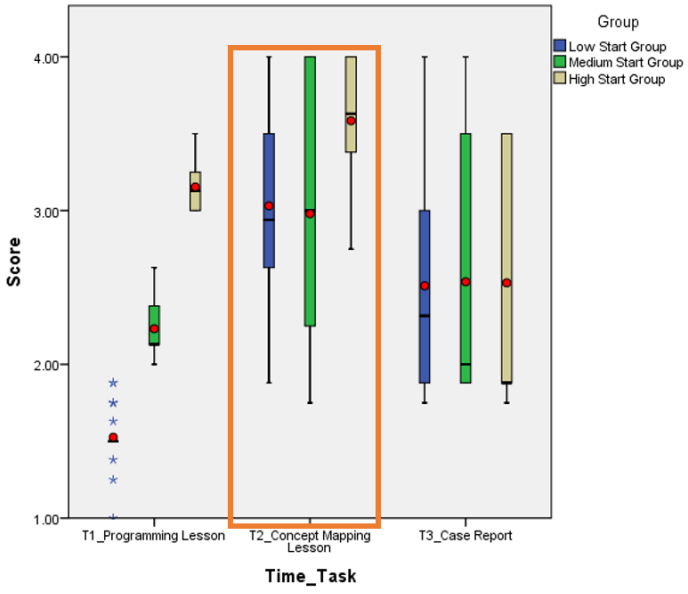


Figure 5.3 Boxplots of TPACK-CT Scores Related to Designing CT Lesson with Concept Mapping Tools among Three Trajectory Groups.

When pre-service teachers designed and implemented CT lessons in an authentic classroom setting, their TPACK-CT demonstration varied depending on how their lessons were aligned into the school context, regardless of their TPACK-CT starting points (the highlighted area in Figure 5.4). For instance, the representative cases whose lesson demonstrated strong TPACK-CT (e.g., Sophie) reflected a solid understanding of weaving the four types of knowledge into the context. In contrast, the representative cases who demonstrated weaker TPACK-CT were found to struggle more in connecting CT knowledge with other knowledge domains in a specific teaching context. Their lessons were more likely to represent TPACK in which they integrate technologies for promoting students' learning. Compared with the previous lessons designed at T1 and T2, the pre-service teachers needed to consider more factors related to planning lessons for authentic classroom settings. These factors required pre-service teachers to make decisions related to the context. For instance, Sophie from the Low Start Group selected to implement technologies that were utilized by the class when implementing CT. Connecting with specific qualitative evidence, Amber's case revealed that the contextual consideration ruled over her TPACK-CT decision since their students were not capable to individually navigate the concept mapping tool. Ella, however, did not design a CT-infused lesson although sufficient technological choices were provided. In this case, Ella's personal factor (e.g., CT competencies) appeared to be more dominant in influencing her TPACK-CT decisions.

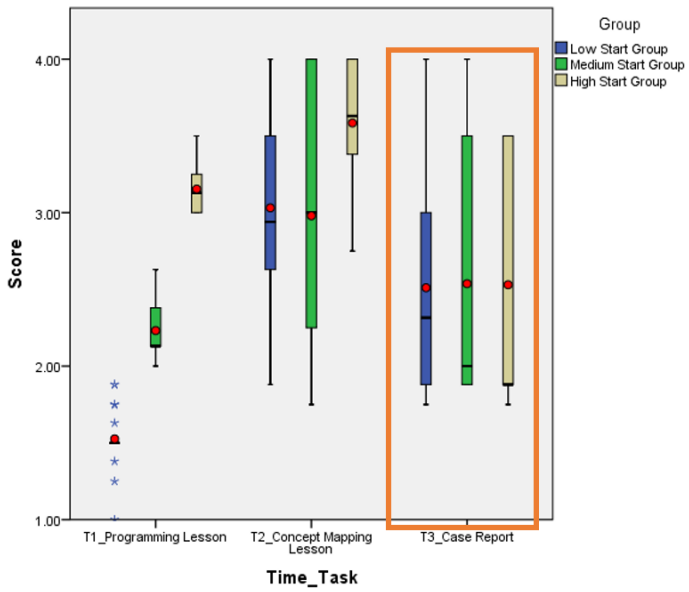


Figure 5.4 Boxplots of TPACK-CT Scores Related to Designing CT Lesson with Technology in Classrooms among Three Trajectory Groups.

Implications and Recommendations

Several implications for educational practice were developed from the findings of the study. These implications include recommendations for preparing pre-service teachers to uptake and apply CT into instruction, supporting pre-service teachers in implementing CT into authentic classrooms, and discussing future research directions.

Preparing pre-service teachers with knowledge and skills for CT implementation in K-8. Recent efforts have been put forth to integrate CT into educational settings (Sadik et al., 2017; Weinberg, 2013). More specifically, such efforts have been focusing on equipping teachers with knowledge of computing tools (e.g., robotics tools) for CT integration (e.g., Buss & Gamboa, 2017; Jona et al., 2014). However, most efforts have mainly targeted infusing CT within STEM education (Angeli et al., 2017; Ehsan, Dandridge, Yeter, & Cardella, 2018; Weintrop et al., 2016), but not

across all content areas specifically for K-8 settings. In fact, CT practices could not only be implemented within higher school contents but also could be integrated to lower graders such as K-2. In particular, implementing CT in K-2 has been documented, including simulation and abstraction (e.g., Ehsan et al., 2018), which were less applied by the pre-service teachers in this study. Results of this dissertation have shown that CT could be implemented through computing technologies into general K-8 settings more broadly instead of being limited to STEM content areas, such as problem decomposition, algorithmic thinking, and data. However, more efforts are still needed for preparing teacher candidates with the knowledge and skills for implementing other CT practices related to simulation, abstraction and parallelization in K-8 settings. This goal could be achieved by providing pre-service teachers with various types of computing technologies to explore and enact CT within their content areas.

Guiding pre-service teachers towards CT implementation in the classroom. Pre-service teachers in this study expressed difficulties in implementing computing technologies in classroom settings, likely as a result of lacking relevant knowledge and experience in teaching in real classrooms. Previous literature shows that preparing pre-service teachers with opportunities to link their theoretical knowledge and practice knowledge can promote their teaching practice in integrating technology (Gomez, Sherin, Griesdorn, & Finn, 2008). Therefore, teacher education programs could consider providing extensive opportunities for pre-service teachers to develop and solidify the necessary knowledge and skills related to integrating computing technology in classroom settings.

Pre-service teachers in this study received only CT training from the redesigned educational technology course alone and did not receive any additional training related to CT. Previous literature studies noted that providing teachers with long-term support resulted in their strong growth in technology integration (e.g., Hofer & Grandgenett, 2012). Furthermore, providing ongoing and consistent support to pre-service teachers positively increased pre-service teachers' attitudes and skills for technology integration (Mayo, Kajs, & Tanguma, 2005). Therefore, teacher preparation programs should take actions to offer systematic and consistent support for pre-service teachers in developing knowledge and skills in relation to implementing computing technologies in the classroom.

Providing substantial support for CT implementation with resources and expert support. One of the major findings of the study revealed insufficient resources, such as technology and expert support, in schools where the pre-service teachers had been placed. In fact, teachers often struggled to effectively integrate technologies into the classroom when lacking the technology and expert support (Groff & Mouza, 2008). Specifically, having limited resources and support for teaching hindered teacher implementing of CT into classrooms (Sentance, & Csizmadia 2017). However, this does not mean that schools should be updating all the technological resources by adding more computing technologies. Some of the computing technologies which could be used to promote students' CT development did not require an extra purchase, such as interactive whiteboards or programming technologies (e.g., Scratch, Pencil Code). However, as reported by the pre-service teachers, there were still restrictions in using such

technologies in the classroom because the Smartboard might not function appropriately, and the laptops were only used for specific purposes such as educational software. Additionally, providing expert support for pre-service teachers might help them develop and implement CT-related practice (e.g., Black et al., 2013). Teacher education programs can work with schools to provide expertise from the university faculty or professional development for teachers (in-service and pre-service) to integrate CT within the school curricula.

Ensuring educational initiatives related to CT implementation in the classroom. Although CT has been recognized as an important skill for the 21st century and has been addressed in educational standards in K-12 (e.g., CCSS, 2010; NGSS 2010), it has not been implemented within K-12 in significant ways (NRC, 2010; Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013). In particular, it was not fully recognized by most of the schools included in this study. In fact, the meso context level, which involves the school climate related to values and applying technology, plays a central role in carrying out educational initiatives from the macro level (e.g., educational policy) to the micro level (e.g., classroom) (Porras-Hernández, & Salinas-Amescua; 2013). Therefore, policymakers, researchers and school administrators should convene efforts to push CT into K-12 settings, followed by providing sufficient and adequate support for schools to gradually embed CT into their instructional agendas.

Future directions related to educational research in pre-service teacher learning with CT. This dissertation examined pre-service teachers' learning trajectories in relation to CT implementation at specific time points throughout their participation in a

redesigned educational technology course. In particular, this dissertation piloted a follow-up section to examine pre-service teachers' long-term enactment of CT in their classroom settings. Future research should follow longitudinal designs related to how pre-service teachers develop and apply CT into classrooms, in order to more precisely determine factors that hinder or promote CT development and implementation. In addition, this dissertation provided one approach in preparing pre-service teachers in learning and implementing CT. Other approaches such as introducing CT along with the method courses provided by the teacher education programs may also be promising to help pre-service teachers make linkages between CT practices and content-specific teaching activities (e.g., Yadav et al., 2017). Therefore, future research could continue exploring effective approaches to facilitate pre-service teachers' CT development in order to successfully implement CT in the classroom. Moreover, previous research studies reflected a need to showcase actual CT implementation examples in classroom settings (e.g., Mouza et al., 2017b). This dissertation obtained a relatively larger sample size which resulted in providing more detailed and nuanced information about specific CT implementation examples in K-8. Hence, future research could expand the sample size or collect large data sets to capture specific and applicable CT practices in K-12 settings (Barr & Stephenson, 2011).

Furthermore, although the Phase II quantitative results showed the increased TPACK-CT scores between the programming task and the concept mapping task, these improvements couldn't conclude that the pre-service teachers truly improved their TPACK-CT scores. Based on the study findings in chapter 4 and the discussion at the

beginning of chapter 5, pre-service teachers from this study were more comfortable and confident in navigating concept mapping tools than the programming tools. Therefore, the nature of the computing technologies assigned to each assignment may influence the pre-service teachers' TPACK-CT representations at these time points. To more precisely capture pre-service teachers' TPACK-CT development, future research can examine pre-service teachers' TPACK-CT scores using a quasi-experimental design. A group of pre-service teachers will be assigned to one of the two conditions. The first condition will have the pre-service teachers experience the exact tasks used in this study. These tasks follow the same sequential order presented in this study. The second condition will have the pre-service teachers experience the same tasks but will reverse the task orders by placing the concept mapping task prior to the programming task and keeping the case report assignment as the final task.

Using mixed-methods methodology in educational research. This work is grounded on the mixed-methods research design by Creswell and Plano-Clark. Creswell and Plano-Clark's (2017) defined mixed-methods research as a methodology that combine quantitative and qualitative approaches to "precisely and rigorously responded to the research questions", incorporate "two forms of data and their results", design "logic and procedures for conducting the study" and "frames these procedures within theory and philosophy" (p. 5). Compared with other scholars' interpretations of mixed methods design, Creswell and Plano-Clarks' (2017) definition recognized the importance of grounding mixed method designs in theoretical foundations and philosophical

assumptions which precisely distinguish the mixed-methods approach from a singular qualitative or quantitative method.

Previous research studies related to preparing pre-service teachers in learning and implementing CT reflected a need for using multiple data sources to illustrate pre-service teachers' learning trajectories. For instance, Lehtinen et al. (2016) stated that interviews have a potential to understanding preservice teachers' views regarding technology integration in addition to using survey data. Moreover, following pre-service teachers after they left the course would provide more insights about their actual integration of simulations in their practice (Lehtinen et al., 2016). Therefore, when I investigated how preservice teachers used technology to develop CT knowledge and skillsets in this study, I planned to obtain multiple data sources to portray and instantiate pre-service's CT implementation over time. With this purpose in mind, I sought to collect quantitative and qualitative data and to plan an analytic and integrated approach in the interpretation of the data sets.

This study presents an example of utilizing mixed-methods approaches in research design and methodological selections. In particular, this study demonstrates how quantitative and qualitative data could be integrated together using a joint display (Figure 4.4). Joint displays as visual representations allow researchers to compare quantitative and qualitative data and present the congruent or divergent elements of both data strands ((Bustamante, 2017; Fetters, Curry & Creswell, 2013; Ziegler, 2014). Therefore, future research in relevant topics could consider adopting the mixed-methods design framework and more importantly, to advance the integrated approaches to facilitate the process of

data integration to achieve more cohesive and comprehensive interpretation of various data sets.

Limitations of the Study

The study is limited in two primary aspects. First, this study interviewed participants one year after they participated in the redesigned educational technology course. Capturing retrospective accounts of participants can cause challenges for the trustworthiness of findings. To address this limitation, a review sheet was provided for pre-service teachers during the interview to help them retrieve information when it was needed. In particular, the review sheet was designed to provide essential (e.g., CT definitions and practical examples) and specific (e.g., individual interviewee's responses to the survey questions at end of the course) information to help the interview participants retrieve the information learned from the redesigned educational technology course.

Secondly, the study focused on examining one teacher education program and did not obtain a representative sample size for all the teacher candidates in the United States. Although the obtained effect for group-by-time interaction among the three trajectory groups presented a large effect size (eta squared = .06), the power analysis indicated that more participants are needed in order to achieve a medium effect size (d =.25) for this study (Cohen, 1988; Murphy & Myors, 2004). Therefore, the study results might not be applicable for generalizing purpose. Although the study did not obtain a large sample size, the study results present rich and enlightening information from various data sources related to teacher learning of CT implementation. Therefore, the study results provide

several implications to the teacher education program in relation to prepare pre-service teachers in CT enactment.

Conclusion

Before incorporating CT into K-8 teaching settings, it is important to know what CT learning and implementation looks like for pre-service teachers. This work depicts teacher knowledge in relation to CT implementation in K-12 settings, as well as underlining factors that influence teachers' decisions in infusing CT in classrooms. The non-linear learning trajectories of the pre-service teachers in this study showed that pre-service teachers' knowledge related to CT implementation is neither static nor decontextualized. In fact, the study showed that pre-service teachers' knowledge related to CT implementation could alter based on specific computing technologies. Although pre-service teachers' learning trajectories continued to change at different time points, the results of the study reflected that their CT enactments could be malleable. Therefore, efforts to continue to facilitate pre-service teachers in developing CT practices rely on collaboration from different sectors, including the teacher preparation program, partnered schools, and educational policy.

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Appendix A

INTERVIEW PROTOCOL

Before the interview:

The researcher will send the interviewee a review sheet which provides the definition of Computational Thinking. Additionally, this review sheet includes different types of technology which were introduced in (The redesigned educational technology course title). Moreover, the review sheet contains participants' previous responses to three open-ended questions which were asked in their end-of-course survey in Spring 2017.

On the interview day:

The researcher will introduce herself to the interviewees and briefly explain to them the research project, including goals, rationales, procedures and methodologies. After the brief introduction, the researcher will provide two copies of the consent form and go over the information with each interviewee. If the interviewee has no questions, he/she will be asked to sign both consent forms. The researcher will keep one of the consent forms while the interviewee will keep the second copy. The researcher will ask the interviewee to also provide a brief self-introduction before the interview. The voice recorder will be turned on before the interviewee starts his/her self-introduction.

Interview questions:

Stage 1: Getting to know the interviewee's teaching background, current role and responsibilities in his/her student teaching experience.

- Can you provide a brief introduction of yourself, including your concentration within the ETE program, year, current corusework and teaching experience?
- Can you describe your current student teaching placement, including your role and responsibilities, subjects taught, available classroom technology, classroom procedures, student demographics, school contexts (urban, suburban or urban) and so forth?

Stage 2: Understanding interviewee's decisions related to CT implementation in his/her student teaching experience.

- It has been a while since you completed the course (The redesigned educational technology course title). In this course, you were introduced to different technologies which can be used for developing Computational Thinking-infused lessons. Prior to this interview, you were provided with a review sheet through email. Based on the information provided in Part I of the review sheet,
    - In what way do you think a CT-infused lesson can be implemented in a general K-8 classroom setting?

- Based on the information provided in Part II of the review sheet,

- In your opinion, what types of technology or technologies could be used to implement a CT-infused lesson?
    - Can you provide an example?
    - Is there other technology that you think could be used for CT implementation? Can you provide an example?
- What would be the benefits of using such technology in a CT-infused lesson (e.g., facilitating students' learning in both CT and content knowledge, motivating students to learn etc.)?
- What factors influence a teacher's decision to integrate technology into a CT-infused lesson?

- Based on the information provided in Part III of the review sheet,
    - Do you still hold the same opinion related to the definition of CT and ways of implementing CT in the classroom? If no, can you explain your thoughts to the three questions listed in Part III of the review sheet, including CT definition and the ways of implementing it in the classroom?
    - Have you ever implemented any CT activities or lessons listed in your survey responses during your student teaching experience?
        - What were the reasons that make you implement (not implement) these CT activities or lessons?
        - What types of technology did you use to implement these CT related activities?

- Have you ever had an opportunity to implement CT activities or lessons which are not mentioned in your survey responses?
    - If so, please describe the CT activities/lessons and the technology that you implemented in the classrooms.
    - If not, please explain why.
- Have you observed your clinical educator or other teacher at your student teaching placement teach a CT-related activity/lesson?
    - If so, please describe the CT activity/lesson (e.g., objectives, CT concepts, use of technology etc..).
    - If not, please share your thoughts as to why CT activity/lesson have not been introduced in your student teaching placement or school.
- If you are given an opportunity to design and implement a CT activity or lesson in your current or future teaching placement, how will you plan the activity or lesson?
    - (e.g., Describe the learning objectives, content areas, technology, CT concepts and activities, pedagogical approaches etc..)

Stage 3: Exploring other factors that may contribute to explain interviewees' decisions about CT implementation in their student teaching experience.

- What other types of training related to Computational Thinking, if any, have you received after taking the redesigned educational technology course at UD?

- What school-wide activities related to CT (e.g., CT training, implementation or CT-related activities) have you observed in your field placements?
- What information and resources related to CT have you noticed or received either on the UD campus or in K-12 settings? Can you list some of these resources if any?
- What benefits or opportunities have you noticed, if any, for K-8 teachers to implement CT into their classrooms?
- What are your concerns and foreseen challenges that will hold back your decision to implement CT-infused lessons into your classroom? (e.g., CT knowledge; confidence and comfort; classroom climate, technology, lack of support etc..)

After the interview:

At the end of the interview, the researcher will check with the interviewee if he/she has any other questions related to the research project. If he/she has questions, the researcher will further explain the research project to address their questions. Additionally, the researcher will inform the interviewee that he/she may be contacted again for some follow-up questions if the researcher find additional information is needed to clarify participants' interview responses. The researcher will also remind the interviewee that an electronic gift card will be sent to his/her UD email within three weeks.

Appendix B

INSTITUTIONAL REVIEW BOARD DOCUMENTS

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	April 3, 2018
TO:	Hui Yang
FROM:	University of Delaware IRB
STUDY TITLE:	[1217066-1] Doctoral Dissertation: Exploring and Exemplifying the Development of Pre-service Teachers' Computational Thinking in the Context of Technology Integration
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	April 3, 2018
EXPIRATION DATE:	April 2, 2019
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(6,7)*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Generated on IRBNet

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.

Generated on IRBNet

Appendix C

PARTICIPANT RECRUITMENT EMAIL

Dear _____,

My name is Hui Yang ("Mocha") and I am a doctoral student in the School of Education at UD. Previously, I was one of the teaching assistants for EDUC *** (The redesigned educational technology course title) which you enrolled in Spring 2017. I would like to invite you to participate in my dissertation study. You will receive a $20 gift card as gratitude if you decide to participate.

You are selected as a potential participant for my dissertation study because you had learned about the concept of Computational Thinking (CT), as well as integrated CT ideas and content areas through the use of technology, during your participation in EDUC *** (The redesigned educational technology course title). For my dissertation, I am particularly interested in learning about the way (if any) you have applied CT concepts and practices into your current student teaching experience.

If you agree to participate, I will interview you for approximately 45 minutes to 1 hour. The purpose of the interview is to focus on your decisions and thoughts related to CT

implementation in classroom settings. The interview can take place on the UD campus or through a phone call. The interview will be audiotaped.

If you are interested in participating, please let me know by April 20, 2018 and we will schedule a time and method (face-to-face or phone) for the interview. If you have any questions about the study, I can be reached at 620-757-3005 or huiy@udel.edu.

Sincerely,

Hui Yang ("Mocha")

School of Education

University of Delaware

Appendix D

REVIEW SHEET FOR INTERVIEWEE

Part I: Computational Thinking Concepts in K-12 (CSTA & ISTE, 2011).

The Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) presented nine Computational Thinking (CT) concepts and capabilities for K-12 schools. These core CT concepts are:

(a) problem decomposition: “breaking down complex problems into more manageable parts”.

(b) algorithmic thinking: “using a precise sequence of steps or instructions to solve problems”.

(c) abstraction: “reducing complexity to define a main idea/applying abstraction to develop models of natural or artificial phenomena”.

(d) data collection, analysis and representation: “accessing, evaluating and representing data using words, images or models”.

(e) automation: “using digital tools to automate solutions”.

(f) parallelization: “making things happen at the same time/organizing resources to simultaneously carry out tasks that help achieve a common goal”.

(g) simulation: “representing a process”.

Part II: Computing Technology and Its Related Activity and Practices Introduced in EDUC *** (The redesigned educational technology course title)**: Integrating Technology in Education.**

Technology	**Activity & Related Practices**
Interactive Whiteboards	Identify two interactive whiteboard resources that support key CT skills: *Modeling* (e.g., a resource that can be used to represent a phenomenon such as prey and predator relationship); *Sequencing* (a resource that could be used to sequence events); *Data* (e.g., a resource that could be used to represent data such as a graph); and *Sorting* (e.g., a resource that could be used to organize information)
Programming Hour of Code Scratch	*CS unplugged* (activity done without computers to introduce algorithms) *Hour of Code*: Completion of a Grades 2-8 activity *Introduction to Scratch Programming*: Scratch is an object oriented programming language Review lessons that support the use of Scratch: ScratchED Design of a learning activity in a content area that involves Scratch Programming/Reflection

Concept Mapping Tools	Design of a learning activity that uses concept mapping in a content area to support student development of CT skills, such as decompose a mathematical problem, model abstraction (e.g., life cycle of a butterfly), sequence events in a story or plan essay execution.
Data	Introduction to Internet Research including use of keywords, boolean logic and operators and evaluation of online content
Collaboration tools	Select and read an article on multiple approaches to developing CT: board games, robotics, programming. Use of a collaboration tool to present the reading to classmates.

Part III: Your Responses to Three Open-ended Questions at the End of EDUC * Course** (The redesigned educational technology course title)**.**

Question 1: What do you think the term Computational Thinking mean?

Your Response: *(The researcher will provide the interview's pervious responses to this question.)*

Question 2: Do you think Computational Thinking can be integrated into the classroom? If yes, how would you implement Computational Thinking into your future classroom? If no, why do you think Computational Thinking cannot be integrated into the classroom?

Your Response: *(The researcher will provide the interview's pervious responses to this question.)*

Question 3: How can technologies be used to help develop school students' Computational Thinking skills?

Your Response: *(The researcher will provide the interview's pervious responses to this question.)*

Appendix E

CONSENT FORM

University of Delaware *IRB Approved From: 04/03/2018 to 04/02/2019*

INFORMED CONSENT TO PARTICIPATE IN RESEARCH

Title of Project: Doctoral Dissertation: Exploring and Exemplifying the Development of Pre-service Teachers' Computational Thinking in the Context of Technology Integration

Principal Investigator(s): Hui Yang

You are being invited to participate in a research study. This consent form tells you about the study including its purpose, what you will be asked to do if you decide to take part, and the risks and benefits of participating in the study. Please read the information below and ask me any questions you may have before you decide whether or not you agree to participate. Your participation is voluntary and you can refuse to participate or withdraw at any time without penalty. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?

This study is being conducted as a part of my doctoral dissertation study. The purpose of my dissertation is to learn about the learning trajectories of pre-service teachers' development of Computational Thinking (CT) concepts and their CT implementation in K-8 classroom settings.

You will be one of approximately eighteen participants in this study. You are being asked to participate because you previously enrolled and completed the EDUC 387 Integrating Technology in Education course which introduced you with CT concepts and computing tools that can be used in conjunction with content areas.

WHAT WILL YOU BE ASKED TO DO?

As part of this study you will be asked to participate in an interview about your relevant experiences in Computational Thinking implementation in your student teaching experience. The interview will last approximately 45 minutes to 1 hour and will take place in a location of your choice on campus or through a phone call. The interview will be audiotaped.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

The researchers do not expect your participation in this study to expose you to any risks different from those you would encounter in daily life. Pseudonyms will be utilized to protect your identity and all other identifiable information.

WHAT ARE THE POTENTIAL BENEFITS?

Although there is no direct benefit to you, knowledge gained from this study may contribute to our understanding of how pre-service teachers perceive and implement Computational Thinking in their future classrooms, which can be used to inform future course designs for pre-service teachers.

HOW WILL CONFIDENTIALITY BE MAINTAINED? WHO MAY KNOW THAT YOU PARTICIPATED IN THIS RESEARCH?

The information that you provide will remain confidential. Your identifying information will be known to the researchers, but will not be shared publicly. All identifying information will not appear on transcripts of

Participant's Initials _____

the interviews. Any reference made to you, the participant, in written reports of the analyses from this study will use pseudonyms for you and the institution in which you are currently employed or attending.

The digital audio files recorded for this study will be stripped of all personal identifiers, encrypted, and stored in protected files. Audio files recorded during the interviews will be erased from all computers and servers after transcription is completed, and no later than December 31, 2018. The printed copies of the transcribed interviews, when not being used by the researcher, will be stored in a locked filing cabinet in a locked office at UD. Paper transcripts will be shredded and thrown away after the study is finished (no later than 12/31/2019). Consent forms will be stored in a locked file cabinet in a locked office at the University of Delaware and destroyed no later than December 31, 2019.

Research results will be reported as case studies and in aggregate across the participants. All reports using direct quotes will be devoid of any references to you, as only pseudonyms will be used. Every effort will be made to protect your identity. If the research from this study is used in a presentation or publication any personable identifiable information *will not* be shared.

The confidentiality of your records will be protected to the extent permitted by law. Your research records may be viewed by the University of Delaware Institutional Review Board, which is a committee formally designated to approve, monitor, and review biomedical and behavioral research involving humans. Records relating to this research will be kept for at least three years after the research study has been completed.

WILL THERE BE ANY COSTS TO YOU FOR PARTICIPATING IN THIS RESEARCH?

There are no costs associated with participating in this study.

WILL YOU RECEIVE ANY COMPENSATION FOR PARTICIPATION?

You will receive a $20 gift card through email after the interview.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your decision to withdraw, or not participate, will not influence current or future relationships with the University of Delaware. If at any time you decide to end your participation in this research study, please inform the research team by telling the investigators through phone or e-mail contact.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please contact the Principal Investigator, Hui Yang, at (620) 757-3005 or huiy@udel.edu, or the faculty supervisor of this research, Dr. Chrystalla Mouza, at (302)831-3108 or cmouza@udel.edu.

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at hsrb-research@udel.edu or (302) 831-2137.

Participant's Initials _____

Your signature on this form means that: 1) you are at least 18 years old; 2) you have read and understand the information given in this form; 3) you have asked any questions you have about the research and the questions have been answered to your satisfaction; and 4) you accept the terms in the form and volunteer to participate in the study. You will be given a copy of this form to keep.

Printed Name of Participant	Signature of Participant	Date
Person Obtaining Consent (PRINTED NAME)	Person Obtaining Consent (SIGNATURE)	Date

Participant's Initials _____