ABSTRACT

SMILING, JAMES F. Characterization of Highly Active Teacher Learners' Participation and TPACK Knowledge While Engaging in a Teaching Mathematics with Technology MOOC for Mathematics Educators. (Under the direction of Dr. Karen Hollebrands).

As the demand for integrating educational technologies within the mathematics teaching curriculum increases, there is a growing need for teachers to develop the competencies and skills required for effective technology integration into their teaching practices. Massive Open Online Courses for Educators (MOOC-Eds) offer teachers opportunities for professional development. Consequently, it is worthwhile to explore the impact of active participation in these professional learning courses. The purpose of this study was to gain a deeper understanding of the distinct types of knowledge teachers gained from active participation in the *Teaching Mathematics with Technology (TMT)* MOOC-Ed using discussion forums as a space to assess teacher learning.

A concurrent embedded mixed methods design (QUAN + QUAL) was employed for this study. Both quantitative and qualitative data was collected and analyzed separately then data was mixed for joint analysis. Two theoretical frameworks were employed to frame this study and support data collection, analysis, and interpreting results. The Productive Online Discussion Model served as an a priori coding frame employed to analyze the dispositions and learner actions of the discussion forum contributions of active teacher learners. A pre- and post-TPACK survey measuring technological knowledge (TK), pedagogical knowledge (PK), content knowledge (CK), and technological pedagogical content knowledge (TPACK) was administered to evaluate active teacher learners change in knowledge before and after the MOOC-Ed experience.

Qualitative results from the study indicated that overall, discussions to comprehend occurred most frequently in the discussion forums. Results also showed the frequency of forum

contributions categorized as discussing to critique, construct knowledge, and share improved understanding increased during the MOOC-Ed while discussions to comprehend decreased. Quantitative results showed statistically significant growth with large effect size from pre- to post- survey in the TPACK domain for active and highly active teacher learners. Teachers reported the greatest effect on their professional learning experience was increased knowledge of combining pedagogical techniques with technological tools and their content knowledge to teach student-centered lessons. Integrated results indicated that there was a meaningful relationship between highly active teacher learners TPACK growth and their distinct forum contributions that sought to critique, construct knowledge, and share improved understanding.

Implications for research emphasize the importance of understanding the different contexts in which teachers teach and designing online courses to meet their diverse learning needs using research-based principles. Additionally, teachers of online learning should consider implementing authentic tasks that contain relevant content, discussion forum questioning that elicits higher order thinking, and opportunities for reflection. Future research is suggested in the areas of employing language technologies (i.e., text mining tools) to explore online interactions and gain insight into user satisfaction and increasing learner engagement and examining to impact of duration of how duration affects participation and attrition rates in professional learning courses.

Characterization of Highly Active Teacher Learners' Participation and TPACK Knowledge While Engaging in a Teaching Mathematics with Technology MOOC for Mathematics Educators

by
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APPROVED BY:

Dr. Karen Hollebrands Committee Chair	Dr. Robin Anderson
Dr. Gemma Mojica	Dr. Kevin Oliver

DEDICATION

This work is dedicated to my wife, Ronda Smiling, and our five eternal gifts from God–Caroline, Colleen, Abigail, Adeline, and Lucas for your sacrificial love, patience, and endless encouragement. Also, my father and mother for their unwavering support throughout my life. Most importantly, I thank my Savior, the Lord Jesus Christ for giving me the clarity of mind, fortitude, and resolve to journey through this season of self-discovery.

BIOGRAPHY

James Frederick Smiling was born on October 26, 1976, in rural southeastern North Carolina to parents Carson and Jane B. Smiling. James has three siblings-Christopher (deceased), Regina, and Patrick. He is an enrolled member of the Lumbee Tribe of North Carolina, the largest Native American tribe in the eastern United States.

James attended the University of North Carolina-Pembroke (UNCP), a Native Serving Nontribal University, where he was a recipient of the First Americans' Teacher Education (FATE) Program Scholarship and received the UNCP Chancellor's Commendations for Outstanding Scholarship in 2007 and Outstanding Leadership in 2008. He graduated with a Bachelor of Science in Secondary Mathematics Education in 2009. While serving his community as a mathematics teacher at his alma mater Purnell Swett High School, he decided to pursue an advanced degree in mathematics education in 2012. James completed his Master of Arts in Secondary Mathematics Education at UNCP in spring 2014. Upon graduation, James continued to fulfill his role as a mathematics teacher and department chairperson at Purnell Swett while teaching as an adjunct instructor in the Mathematics and Computer Science Department at UNCP and as an online instructor with the North Carolina Virtual Public Schools (NCVPS).

In the summer of 2016, James was honored with the opportunity to serve at the collegiate level and teach as a full-time lecturer at UNCP. Shortly after starting his new position, James began his journey in Fall 2017 at North Carolina State University in the College of Education to pursue his lifelong educational goal of receiving a Ph.D. in Learning and Teaching in STEM. During his time enrolled as a student at NC State University, he continued to serve as a full-time mathematics lecture at UNCP teaching undergraduate and graduate courses while serving on two UNC systems committees and facilitating pre- and in-service teacher workshops. During his second year at NC State, he was approached by his advisor, Dr. Karen Hollebrands to teach a college algebra course on campus in the summer of 2018. This opportunity helped solidify his commitment to the program of study and propelled James to dedicate the next year conducting research with Drs. Karen Hollebrands, Gemma Mojica, and Heather Barker on teacher learning in massive open online courses. This intensive research experience was fundamental in providing a framework for situating his dissertation research within the *Teaching Mathematics with Technology MOOC-Ed* for mathematics educators.

Upon completion of his Ph.D. at North Carolina State University, James will continue to teach and inspire the next generation of educators and professionals at his alma mater, the University of NC-Pembroke in the Mathematics and Computer Science department. Now he will have more time and resources to dedicate to his research interests in teacher learning and professional development.

Through the course of his educational journeys, James has maintained a healthy balance between his professional and personal life. James married the love of his life, Ronda, the same year he started his undergraduate coursework. Two months after landing a teaching position at Purnell Swett in 2009, their eldest daughter Caroline was born on a teacher workday so James could be back at work by Monday morning. On starting the graduate program at UNCP in 2012, James and Ronda’s second daughter Colleen was born during Christmas break. Weeks after graduating from UNCP with his advanced degree, their twins Adeline and Abigail were born during the summer break of 2014. Eight years later, on completion of James’s oral comprehensive exam, Lucas James made his entrance into the world just in time to experience the last seventeen months of this journey with us. I am humbled.

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Living Life

Life is not a race-but indeed a journey. Be honest. Work hard. Be choosy. Say “thank you,” “I love you,” and “great job” to someone each day. Go to church, take time for prayer. The Lord giveth and the Lord taketh. Let your handshake mean more than pen and paper. Love your life and what you have been given, it is not accidental. Search for your purpose and do it as best you can. Dreaming does matter. It allows you to become that which you aspire to be. Laugh often. Appreciate the little things in life and enjoy them. Some of the best things really are free. Do not worry, less wrinkles are more becoming. Forgive, it frees the soul. Take time for yourself-plan for longevity. Recognize the special people you have been blessed to know. Live for today, enjoy the moment ~ Bonnie Mohr

The completion of this dissertation represents the culmination of an intellectually enriching and rewarding journey, and I owe my deepest gratitude to the many individuals who have been involved in helping fulfill this endeavor.

First, I would like to express my deepest gratitude to those who supported me throughout my Ph.D. experience and the completion of my dissertation. I am immensely grateful to my dissertation chair, advisor, mentor, and colleague, ***Dr. Karen Hollebrands*** for her unwavering support, guidance, patience, understanding, and invaluable insights throughout my coursework and this dissertation research process. From my first class in the doctoral program to my defense six years later you have been exemplary in your commitment and dedication to my journey.

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To my parents, ***Carson*** and ***Jane Smiling***, I would not be here today with you. The work ethic you instilled in me has stayed the course. Thank you for all the nights you kept the kids so I could make the four-hour round trip commutes every week for three years. To my wife, ***Ronda,*** and children, ***Caroline, Colleen, Abigail, Adeline,*** and ***Lucas***, this Ph.D. is for you. My accomplishments are not my own and are a reflection of your love and support for each other. This achievement is as much yours as it is mine. I love you forever to the moon and back times infinity.

Lastly, I want to acknowledge the intellectual debt owed to the vast community of researchers, scholars, and writers whose contributions have paved the way for this study. The intellectual heritage that I have drawn upon is a testament to the collective pursuit of knowledge.

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CHAPTER ONE: INTRODUCTION

Classroom teachers are at the heart of educational reform in the United States at the local, state, and national levels. Teacher learning and professional learning are vital for teachers to strengthen pedagogical practices, improve student outcomes, and reform schools (Bleicher, 2014; Borko, 2004). Over the last few decades, there has been no shortage of contexts to support teacher learning. Formal and informal spaces, such as school-based professional development, conferences, workshops, college courses, and summer programs, provide opportunities for teachers to learn (Borko, 2004; Desimone, 2009). Moreover, there has been a sustained effort to measure teacher learning in ways that improve teaching practices and student outcomes (Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001; Korthagen, 2017; Vermunt, 2014).

Traditionally, teacher learning has been studied in the context of formal professional development (PD). Although formal PD has been the typical approach to supporting teachers in their craft, Hoekstra and Korthagen (2011) posit that many studies have shown that these programs fail to produce lasting change in teaching practices. Teachers acknowledge and report the value of effective PD and its significant role in teacher learning (Hoekstra & Korthagen, 2011). However, teachers also affirm that learning occurs outside formal PD within informal learning environments. For example, Hoekstra and Korthagen (2011) noted that teachers find talking with their colleagues or taking online courses as effective informal learning experiences.

Recently, the research community has advanced towards a more sophisticated approach to understanding teacher learning. Opfer and Pedder (2011) conceptualize teacher learning as a complex, multi-dimensional relationship between an organization, teachers, and students that impact the extent to which teachers learn, while Korthagen (2017) asserted that the nature of teacher learning is a multi-dimensional, multi-leveled process occurring between the theoretical, practical, and personal aspects of teaching. Additionally, Dede, Eisenkraft, Frumin, and Hartley (2016) clarify the distinctions between professional development and teacher learning. Professional development is often required, is formal with a fixed duration, and has a set curriculum and instructional strategies with intended outcomes. Teacher learning is voluntary and may be formal or informal with duration and content and initially have uncertain learning outcomes (Dede et al., 2016).

Scholars have known for decades that most educators experience a lack of professional development and teacher preparation for using technology to support student learning (Foulger, Graziano, Schmidt-Crawford & Slykhuis, 2017). According to Whalen (2020), the COVID-19 pandemic revealed significant gaps in how teachers effectively teach with technology so students can continue to learn in distance settings. Teachers reported a lack of knowledge about online teaching tools and strategies and feeling overwhelmed by the number of online resources available (Whalen, 2020). As a result, many teachers actively sought out professional development and learning opportunities to adapt to new ways of teaching and learning using technology.

This chapter will provide an overview of technology use in the mathematics curriculum, a description of MOOCs for teacher learning, a statement of the problem, the purpose of the study, research questions investigated, an overview of methods, and the organization of the dissertation.

Technology Use for Learning in Mathematics Curriculum

As the demand for integrating educational technologies within the mathematics teaching curriculum increases, there is a growing need for teachers to develop the competencies and skills required for effective technology integration into their teaching practices (Daniel, 2020; Gillow-Wiles & Niess, 2014).

In the last twenty years, several sets of mathematical standards and recommendations have been put forth for K-12 mathematics teachers to integrate technologies into their teaching practice. The National Council of Teachers of Mathematics (NCTM, 2000) stated, "technology is essential in teaching and learning mathematics; it influences what is taught and enhances students' learning" (p. 24). In addition, teachers' decision-making and curriculum will play a critical role in how technology impacts students' learning (Dick & Hollebrands, 2011; Lee & Hollebrands, 2008). Dick and Hollebrands (2011) posit that "the '*strategic'* use of technology strengthens mathematics teaching and learning" (p.1), referring to the use of technology tools by teachers and students that spotlight mathematics rather than technology (NCTM, 2015).
In support of NCTM, the Association of Mathematics Teacher Educators (AMTE, 2017) affirms that mathematics teacher education programs "must ensure that all mathematics teachers and teacher candidates have opportunities to acquire the knowledge and experiences needed to incorporate technology in the context of teaching and learning of mathematics" (p. 1). Recently, the International Society for Technology in Education (ISTE, 2017) released the ISTE Standard for Educators, emphasizing the educational benefits of a technology-enhanced learning environment. The standards for mathematical practice outlining the Common Core State Standards of Mathematics (CCSS-M; National Governors Association for Best Practices and the Council of Chief State School Officer [NGA & CCSSO], 2010), encourages mathematics educators to use and facilitate the use of technology tools for student exploration and developing a deeper understanding of concepts. Similarly, the most recent position statement provided by NCTM describes the role of technology within mathematics teaching and learning, stating;

> It is essential that teachers and students have regular access to technologies that support and advance mathematical sense-making, reasoning, problem-solving, and communication. Effective teachers optimize the potential of technology to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics (NCTM, 2015).

With such emphasis on technology use and support for teachers to use technology to teach mathematics, teachers should have access to high quality professional development for just in time teaching. To meet their professional development needs, many choose online courses like MOOCs for their convenience and accessibility.

MOOCs–A Space for Teacher Professional Learning

Massive open online courses (MOOCs) are becoming increasingly popular (Eriksson, Adawi, & Stohr, 2017). The concept of MOOCs started as an opportunity to offer free online learning to unlimited numbers of learners across the globe (O'Donnell, Lawless, Sharp, & O'Donnell, 2015).

MOOCs provide flexible educational learning opportunities where learners can receive peer support from other learners and interact with experts, and access relevant content and materials designed by renowned researchers, teachers, and instructional designers (Conole, 2015).

Two common types of MOOCs are referred to as cMOOCs and xMOOCs. The distinction between each course is based on the different pedagogical approaches for each course type, and this influences the instructional design of the MOOC and the learner experience. cMOOCs have a connectivist-based pedagogical approach (i.e., informal networks) where learning is a socially connected process and users have unlimited autonomy to access content that interests them (O'Donnell, Lawless, Sharp, & O'Donnell, 2015). In contrast, xMOOCs use a content-based behaviorist approach to learning where there is a structured sequence of events and course content is determined by instructional designers (Rodriguez, 2013).

In the last decade, Massive Open Online Courses for Educators (MOOC-Eds) have materialized from the need to provide professional development to K-12 teachers and educational professionals. These courses merge the affordances of both cMOOCs and xMOOCs to offer a unique learning environment. Like xMOOCs, MOOC-Eds "provide a curated set of resources around predefined topics in a centralized learning platform" and "like cMOOCs, MOOC-Eds are purposefully designed around multiple voices and the exchange of multiple perspectives among educators, students, and other experts" (Kellogg & Edelmann, 2015, p. 979).

In 2012 the Friday Institute of Educational Innovation at North Carolina State University (the Friday Institute), launched a MOOC-Ed initiative that offered these PD courses specifically for mathematics and statistics K-12 educators. These MOOCs were developed using four design principles that included *multiple voices* (e.g., expert panels and projects), *self-directed learning* (e.g., asynchronous discussions, and resources), *peer-supported learning* (e.g., conceptual frameworks and peer feedback), and *job-connected learning* (e.g., resources and activities connected to practice) (Kleiman & Wolf, 2015; Kleiman, Wolf, & Frye, 2013). The overarching focus of this MOOC-Ed initiative is to support participants in reaching their professional development goals by providing quality, research-based courses that are accessible and cost-effective (Kellogg & Edelmann, 2015; Kleiman & Wolf, 2015).

Statement of the Problem

Although the CCSS-M standards and mathematics organizational recommendations emphasize the use of technology in mathematics educator training and teaching; research suggests that there is a continuing need to provide mathematics teachers with professional development opportunities focused on integrating technological tools in their teaching practices (Hollebrands & Lee, 2020). The recent OECD (2017) PISA international research on students' use of technology found that students did not perform better on assessments when taught using online learning tools and resources. In addition, the study suggested that teachers were pedagogically underprepared to effectively integrate technological tools into the curriculum (OECD, 2017).

The current challenges have forced educators to adopt online technologies rapidly because of the global COVID-19 pandemic. As learning was consistently moving from face-to-face environments to online and distance settings, mathematics teachers were compelled to become technologically competent in new ways of teaching and learning (Marpa, 2021). In turn, these constraints have had a positive impact on mathematics teachers seeking professional development opportunities to serve the increased learning needs of their students. With the growing need and demand for professional development, MOOC-Eds afford educators the opportunity and flexibility to leverage these learning venues for their personal and professional learning needs. Subsequently, as MOOC-Ed courses become more prevalent, it is advantageous for the research community to explore the potential impact that active participation can have on teachers' mathematics learning.

Purpose of the Study

As the popularity of MOOCs employed for professional development in education increases, it is worthwhile to explore the impact of active participation on educators' professional learning in these courses (Ertmer, Sadaf, & Ertmer, 2011). MOOC-Eds contribute to the sharing of ideas, resources, and professional experiences in collaborative learning spaces for teachers. Additionally, as teachers engage in this networked environment with each other and course content, they add to their individual and collective knowledge (Borba, Askar, Engelbrecht, Gadanidis, Llinares, & Aguilar, 2016). Considering this, the aim of this study is to gain a deeper understanding of the distinct types of knowledge teachers gain from participating in MOOC-Eds using discussion forums as a method for assessing learning.

The purpose of this research study is to explore the nature of how educators are engaging in MOOC discussion forums and examine relationships between forum participation and technological pedagogical content knowledge (TPACK). This study will contribute to the current body of research focused on researching interactions in asynchronous learning environments that are learning outcomes-based and seek to improve content understanding for participants. The implications of this study will potentially impact future MOOC-Ed design in developing discussion strategies, activities, and guidelines that will support the learning of MOOC-Ed participants. A mixed-methods approach was used to investigate the following research questions:

1. What is the nature of highly active teacher learners' modes of discussion within forum discussions in the *Teaching Mathematics with Technology* MOOC-Ed?
2. What effect does participation in the *Teaching Mathematics with Technology* MOOC-Ed have on highly active teacher learners' TPACK?

3. What is the nature of the relationship between highly active teacher learners' TPACK and their modes of discussion in the *Teaching Mathematics with Technology* MOOC-Ed?

Overview of Methods

Several data sources were collected to investigate the research questions posed in this study. The self-reported enrollment data was used for demographic information and insight into the goals for participating in the MOOC. This data included organizational affiliation (i.e., school district), school affiliation, gender, the primary area of education, highest educational level attained, years of experience, type of organization (i.e., college/university, school), role at the organization (i.e., K-12 teacher, professor), grade level specialization, anticipated weekly time commitment, ranked goals for enrolling in a MOOC-Ed, technology confidence level, frequency of technology use, and reason for enrolling in the *Teaching Mathematics with Technology* MOOC-Ed. The enrollment data was used primarily for descriptive statistics to describe the sample of participants for this study.

Addressing research question one, qualitative data was collected through the MOOC-Ed discussion forums. Each of units one through four had between one and four discussion prompts. The Productive Online Discussion Model developed by Gao, Wang, and Sun (2009), was employed as an a priori coding frame for the qualitative content analysis of each post to explore patterns and occurrences of learner actions to establish relationships between dispositions (Gibbs, 2007; Miles & Huberman, 1994).

Attending to research question two, quantitative data was collected during the orientation phase and at the end of the five-week course. A 22-question TPACK survey instrument developed and validated by Zelkowski, Gleason, Cox, and Bismarck (2013) were made available to participants when they enrolled in the course. The pre-TPACK survey assessed participants' distinct types of knowledge prior to completing the MOOC-Ed and the post-TPACK survey was available in unit five. The TPACK surveys were analyzed using parametric testing, in particular, paired sample *t*-testing with an emphasis on levels of significance and effect size.

Research question three provides the mixing referred to as the "results point of integration" (Schoonenboom & Johnson, 2017, p. 115), where the participants' patterns of engagement in the discussion forums and statistical measures on the pre-and post-assessment are integrated with the results from each participant pre-and post-TPACK survey data to determine the nature of those relationships and generalize qualitative results (Schoonenboom & Johnson, 2017).

Organization of Dissertation

This dissertation is organized into five chapters. Chapter one presents background information to situate the study, the statement of the problem, the purpose of the study, and the research questions to explore. An overview of methods and a brief synopsis of how the dissertation was organized close the chapter. Chapter two includes a literature review that informs this study in addition to theoretical perspectives and frameworks that give the conceptual basis for analysis in the study. More specifically, the review discusses teacher learning as change, informal learning of teachers, self-directed learning, formal and informal online teacher professional development, discussion forums as informal learning spaces, engagement in forum discussions, and qualitative analysis of these forums. Chapter three presents the methodology for this study, justification for the choice of study design, instrument use, and data collection, and methods of data analysis. Chapter four describes the findings of the study through examination of each research question. Chapter five interprets and discusses the significant findings of the study, limitations, research implications, and suggestions for future research.

CHAPTER 2: LITERATURE REVIEW

Introduction

The review for this study provides a synthesis of literature focused on teacher learning. This review opens with a broad overview of teacher learning and transitions to informal teacher learning with an emphasis on self-directed learning (SDL). In the context of online professional development, teachers make decisions to participate because they are motivated to engage in informal learning. Teachers use self-directed learning strategies to gain new knowledge that is relevant to their professional teaching practice.

Teacher Learning in the Context of Change

Much research has been conducted in the last few decades on the notion of learning in teacher education. In general, Gagne (1985) proposed learning as “a change in human disposition or capacity that persists over a period of time and is not simply ascribable to processes of growth” (p. 2). This definition of learning establishes a foundation for understanding teacher learning and professional learning. Guskey (1986) contributed that teacher learning is inextricably connected to teacher change, for which the learning process for teachers is associated with classroom experiences with successful student outcomes. Changes in teachers’ instructional practices results from systematic attempts to transform teachers’ classroom practices (e.g., staff development). When these changes enhance students’ learning outcomes, teachers experience changes in attitudes and beliefs. Bell and Gilbert (1994) conducted a longitudinal study and observed teachers simultaneously developed their beliefs and attitudes, classroom practices, and teacher identity while learning. They concluded that teacher learning was an integrated process experienced in personal, social, and professional dimensions.

Bell and Gilberts findings seem to support the definition Guskey would provide several years later.

Guskey (2000) provided a formal definition of teacher learning concerning professional learning as “those processes and activities designed to enhance the professional knowledge, skills, and attitudes of educators so that they might, in turn, improve the learning of students” (p. 16). Clarke and Hollingsworth (2002) suggested that Guskey’s notion of ‘change’ be categorized as growth or learning where teachers are referenced as learners within a learning community. The researchers revised Gagne’s definition of learning to include teachers while emphasizing the importance of understanding the process and conditions that support and promote teacher learning (Clarke and Hollingsworth, 2002). Whereas Fullan (1982) and Guskey (1986), among others, designed models illustrating the nature of teacher professional growth as a linear process, Clarke, and Hollingsworth (2002) submitted the interconnected model of professional growth to represent the complex processes involved in teacher learning. The model consists of four domains, including the *personal domain* (knowledge, beliefs, and attitudes), the *domain of practice* (implementing new practices/approaches), *the domain of consequence* (notable outcomes and consequences), and the *external domain* (resources and support) (Clarke & Hollingsworth, 2002). The model promotes change through the mediating processes of *enactment* and *reflection*. Enactment is defined as "translating a belief or a pedagogical model into action" (p. 950), while reflection is a process of "active, persistent and careful consideration" (Clarke & Hollingsworth, 2002, p. 954).

Opfer and Pedder (2011) urged the research community to conceptualize teacher learning as a complex system involving multiple systems (i.e., teacher, activities, institution, and school system) that impact the extent to which teachers learn. More recently, Korthagen (2017) asserted that the nature of teacher learning is a multi-dimensional, multi-level process occurring between the theoretical, practical, and personal aspects of teaching.

Informal Learning as a Type of Teacher Learning

The teacher-learning process is a complex, multi-dimensional relationship between an organization, teachers, and students. Hoekstra and Korthagen (2011) posit that many studies have shown that formal PD programs fail to produce lasting change in their teaching practices. Teachers acknowledge and report the value of effective PD and its significant role in teacher learning (Hoekstra & Korthagen, 2011). However, teachers also affirm that learning occurs outside of formal PD informal learning environments (e.g., talking with colleagues or online courses) (Hoekstra & Korthagen, 2011). Dede, Eisenkraft, Frumin, and Hartley (2016) clarify the distinctions between professional development and teacher learning. Professional development is often required, formal with a fixed duration, and set curriculum and instructional strategies with intended outcomes. Teacher learning is voluntary and may be formal or informal with duration, content, learning, and initially uncertain outcomes.

Watkins and Marsick (1992) defined informal learning as “learning from experience that takes place outside formally structured, institutionally sponsored, classroom-based activities” (p. 288). Later, Hoekstra and Korthagen (2011) would provide a more nuanced definition of informal learning within an educational context. They delineated informal learning as "learning taking place where no PD trajectory or learning community has been explicitly organized to foster teacher learning" (p. 76) (cf. Billet, 2004; Eraut, 2004). Researchers have identified that teachers learn informally in diverse ways, to include workplace settings through experiential learning activities and routine teaching practices (Kwakman, 2003; Lohman & Woolf, 2001; Van Eekelen, Vermunt,

& Boshuizen, 2006). According to Van Eekelen et al. (2006), a teacher's 'will to learn' (want to learn, experiment, and explore new experiences) will precede any learning activity in the workplace. Further, teachers must be proactive in their desire to learn among environmental, personal, and professional factors that may or may not influence teachers' will to learn.

Self-Directed Learning as a Type of Informal Learning

Informal learning is a broad approach to understanding learning from experience, for which *self-directed learning* (SDL) is a theoretical concept situated within informal learning (Garrison, 1997; Watkins & Marsick, 1992). Malcolm Knowles (1970), an early pioneer of adult education, was one of the first to define the notion of SDL as the following:

> a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing, and implementing appropriate learning strategies, and evaluating learning outcomes (p. 18).

Similarly, other researchers in the field have characterized SDL as professional development arising from the teacher's own initiative (i.e., the process is internally determined and initiated) (cf. Caffarella, 1993; Garrison, 1997). In Knowles's book (1975), *Self-Directed Learning: A Guide for Learners and Teachers*, he focused his discussion on the development of teacher identity and their role in supporting the learning process for students in more formal SDL learning settings (i.e., classroom). However, Tough (1971) studied adult 'learning projects' in informal settings (i.e., at home or on the job) outside of the formal teaching that takes place within a classroom. Watkins and Marsick (1992) contributed that Tough (1982) pointed to 'voluntary purposeful' learning for which an adult learns mostly through their initiative, resembling van Eekelen and colleagues (2006) reference to the 'will to learn.' In discussing the philosophical assumptions fundamental to SDL, Caffarella (1993) echoed Tough, citing that the locus of learning in SDL lies within the individual taking personal ownership of their learning and the processes involved in their learning needs. Like Knowles' definition of SDL, Brookfield (1986) contributed that a central tenet of SDL is a learners' control over establishing their educational goals and determining a measure of criteria for meeting those goals. Brookfield included the importance of independence, where learners actively take responsibility for the planning and organizing of their learning to meet intended outcomes.

Models of Self-Directed Learning

Several models for understanding SDL have been presented to conceptualize various aspects of adult learning. Mocker and Spears (1982) model described four types of lifelong learning: formal, non-formal, informal, and self-directed. Candy (1991) offered a four-dimensional model focused on SDL as a broad concept that included personal autonomy, self-management, learner-control, and autodidaxy (i.e., self-instruction), while Brockett and Hiemstra (1991) offered the Personal Responsibility Orientation (PRO) model. This model's central tenets are *process* defined as the learners recognizing their responsibility in planning, implementing, and evaluating their learning and *goal* delineated as the learners' desire to be responsible for their learning.

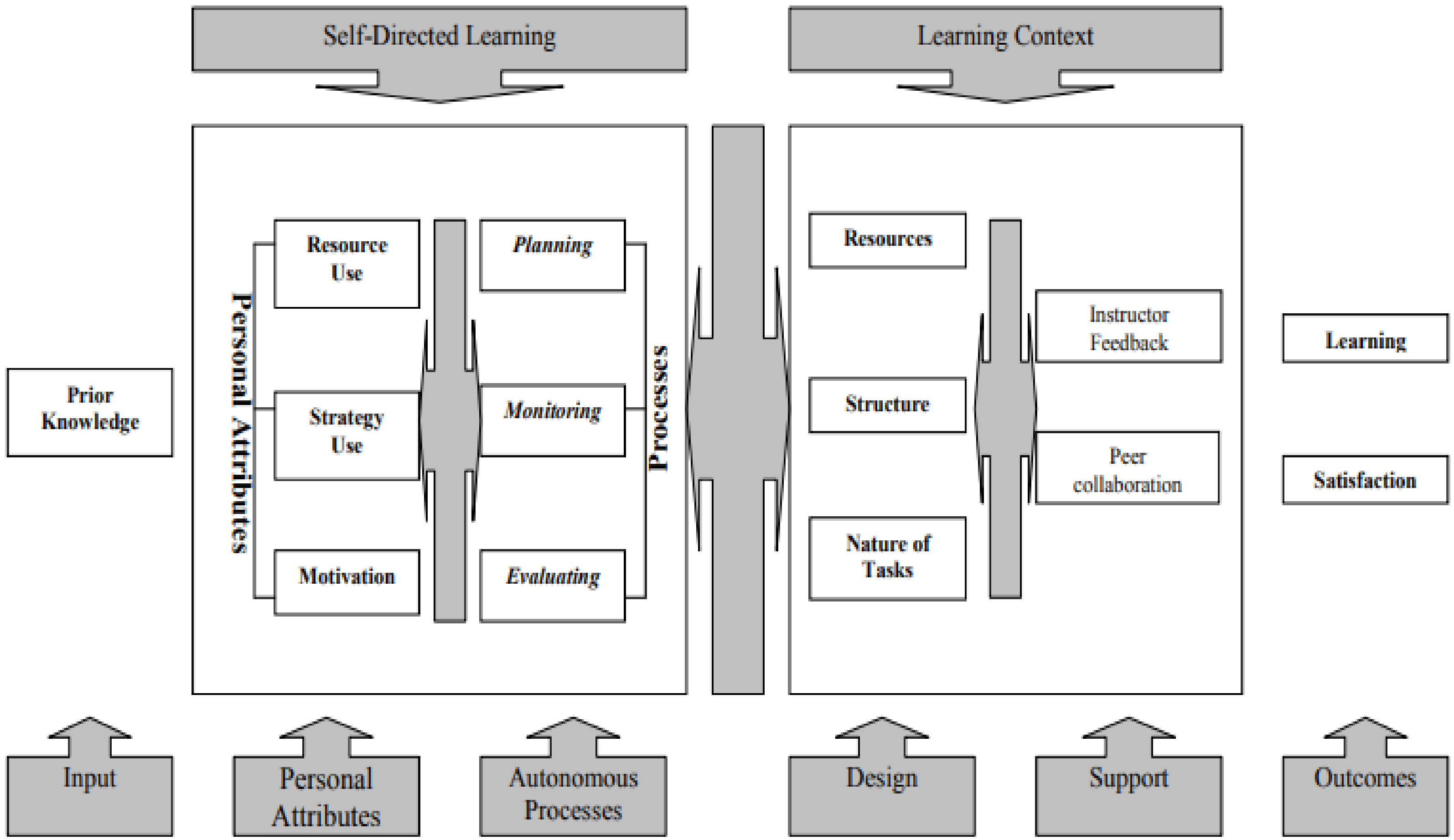
Encouraged by the work of Knowles and Brookfield, Garrison (1997) proposed a three-dimensional model of SDL consisting of (1) motivation, (2) self-monitoring, and (3) self-management. Each model dimension is connected and overlaps with the other dimensions within the model (Garrison, 1997). The first dimension, self-management, relates to task control. The focus is on how external factors (i.e., activities, learning resources, support) affect the learning process. The second dimension comprises self-monitoring, which relates to the cognitive and metacognitive processes involved in the learner's ability to prepare and amend their reasoning to meet their desired learning goals. This domain also references the learner's responsibility in constructing personal meaning of the learning environment. The third dimension, motivation, performs a critical role as a catalyst in initiating and preserving the learner's efforts toward learning and their established cognitive goals. Garrison (1997) distinguishes between *entering motivation* as the learner's dedication to a particular goal and the decision to act on it with *task motivation*, which he defines as "the tendency to focus on and persist in learning activities and goals" (p. 27). Although Garrison contends that the association between motivation and cognition is not well understood, based on the model, motivation directly influences learners self-monitoring and self-management. According to Harnett, St. George, and Dron (2011), motivation is a complex attribute determined by the relationship between the learner and context.

In an analysis of Garrison's model, Zhu, Bonk, and Doo (2020) had 322 MOOC learners complete an online questionnaire to measure SDL dimensions relationships. Quantitative analysis revealed motivation had a direct effect on self-monitoring and an indirect influence on self-management. Also, Garrison suggested that as the demand for network learning (i.e., online learning) increases, the learning responsibility is transferred to the learner from the teacher. The intended symbiotic relationship between responsibility and control will manifest in SDL.

Song and Hill (2007) postulate that these models were beneficial for supporting the understanding of SDL. Although learning context was mentioned in earlier models, Song and Hill argued the influence of context in SDL deserved more attention given the various contexts in distance learning (i.e., virtual classrooms, and online courses) and the influence of these spaces on SDL. In response to the surge in distance learning, Song and Hill developed a conceptual model (see Figure 1.1) adapted for SDL in online learning environments.

Figure 1.1

Self-Directed Learning Conceptual Model (Song & Hill, 2007)



The model includes personal attributes and learning processes from earlier literature and extends context as an environmental element, including factors (i.e., design components and learner supports) within the learning context that impact learning outcomes. Song and Hill (2007) stated that “the addition of the learning context is important in the current climate where there is not one dominating mode of learning” (p. 33). They assert that online learning is intrinsically connected to the personal attributes and processes of SDL. Examining the online learning context influences how much control learners have over executing their learning goals.

Before Song and Hill's model, Vrasidas and Zembylas (2004) designed two e-learning projects for web-based teacher learning using theoretical frameworks of constructivism, situated and distributed cognition, and communities of practice (CoP). Vrasidas and Zemblyas emphasized design and support elements (e.g., ownership, self-reflection) related directly to SDL they suggest are fundamental to online teacher PD projects' success. Their findings supported a revised model and suggested a need for more attention to learning context as an influential factor in online teacher learning.

Self-Directed Learning and Autonomy

In considering the context of online teacher learning, the discussion on SDL would be remiss, not to mention the prominent theme of autonomy when considering the independent nature of learning in online settings. Moore (1986) provided one of the earliest discussions on SDL and distance education. When quoting Boyd’s (1966) definition of adult education, Moore characterized it as ‘fully autonomous or self-directed.' Concerning distance education, Moore emphasized the potential shift in distance teaching should gravitate toward the values of learner freedom and individualism. At the same time, Bagnall (1988) contended that the constraints (i.e., differences between face-to-face and online courses) of distance education could be mitigated through learners acceptance of their autonomy.

Similarly, when referencing massive open online courses (MOOCs), Wiebe, Thompson, and Behrend (2015) contributed that "the aspirational goal and emerging implementation model for MOOCs is one of a free-choice educational space” (p. 252). Wiebe et al. (2015) contended that the MOOC environment has many diverse learners motivated by prior experiences, core ability, and psychological constructs (i.e., self-efficacy). These ongoing negotiations of interactions within a MOOC continue to shape these psychological constructs and practices (Akoglu, 2017). Borba, Askar, Engelbrech, Gadanidis, Llinares, and Aguilar (2016) posited that MOOCs allow learners to participate in any part of the course at their discretion, and MOOCs provide SDL opportunities.

Self-Directed Formal Online Teacher Professional Development

There is no shortage of contexts in which teachers learn. Macià and García (2016) categorized the whole of teacher professional development into three models. The 'craft model' is detailed as learning through classroom experiences, the 'expert model' in which more capable peers train teachers, and the ‘interactive model’ is where teachers acquire knowledge through external sources that lead to teacher change (i.e., pedagogical practices). The authors assert that the ‘interactive’ approach to PD is comprehensive and accounts for several informal teacher learning domains and relates closely to SDL.

To apprehend SDL as a phenomenon, Song and Hill (2007) suggested the necessity of designing effective online SDL environments. In response, there has been a growing body of research aimed at harnessing the utility of SDL to inform instructional design in structuring these environments to support learner autonomy in meeting personal learning goals (Aldon, Arzarello, Panero, Robutti, Taranto & Trgalova, 2019; Al Mamun, Lawrie, & Wright, 2020; Kleiman Wolf, & Frye, 2014; Oswald, 2003; Sze-Yeng & Hussain, 2010; van Merriënboer & Sluijsmans, 2009). For example, Kleiman and Wolf (2015) amplified four dominant design principles, referring to the Friday Institute for Educational Innovation MOOC-Ed (massive open online course for educators) initiative at North Carolina State University (https://place.fi.ncsu.edu/). These principles include self-directed learning, peer-supported learning, job-connected learning, and multiple voices that guide MOOC-Ed courses' design. Kleiman and Wolf contribute that the SDL in the MOOC courses “enables participants to personalize their experience by identifying their own goals, selecting among a rich array of resources, deciding whether, when, and how to engage in discussions and activities to further their own learning and meet their goals" (p. 52).

Based on their empirical research review analysis of forty studies in online teacher professional development (oTPD), Dede, Ketelhut, Whitehous, Breit, and McCloskey (2009) called for more ‘blended’ empirical research studies. They suggest these studies should include whether a program design works well and provide evidence to explain why the design works due to the prevalence of evaluative studies. In line with recommendations from Dede et al. (2009), Hollebrands and Lee (2020) presented an extensive description of how the four design principles (Kleiman & Wolf, 2015) were accomplished across three teacher-oriented mathematics and statistics MOOC-Ed courses. The study examined how the course design elements influenced the learning experiences of 5,767 MOOC-Ed participants across 14-course offerings. Concerning SDL, findings indicated an elevated level of participant agreement that the course design supported personalized learning experiences with the autonomy to engage with resources, explore activities, and participate in discussion forums to meet their learning goals.

Similarly, in a study discussing two MOOC-Eds designed to assist K-5 and statistics teachers, Avineri, Lee, Tran, Lovett, and Gibson (2018) evidenced actionable examples of SDL practices that were implemented in both MOOCs. The MOOCs design emphasized participants establishing personal learning goals with initial surveys and resources and materials that teachers could readily use in their teaching practices. The study aimed to determine how teachers engaged in the PD and how the experience influenced their teaching practices. After analyzing exit surveys, Avineri and colleagues found that participants addressed changes in their pedagogical approach to teaching. Other participants reported a more refined understanding of student thinking and improved mathematics content knowledge.

Using a blended (i.e., online, and face-to-face) approach to teacher learning, Anderson, Boaler, and Diekmann (2018) conducted a one-year study with 40-fifth grade teachers spanning eight school districts to support teachers' understanding of the mathematical growth mindset. The online course design offered SDL elements with self-paced instruction and afforded flexibility, giving teachers time to access course modules. At the same time, Anderson and colleagues fit the role of 'expert' facilitating PD as teachers and teacher coaches. Additionally, during the PD's online portion, teachers were given time to reflect on activities (i.e., journal questions, lessons, and discussion forums). Researchers agree that online course design should consider time constraints on teachers and include activities that directly impact their learning and teaching to benefit self-directed learners (Hollebrands & Lee, 2020). Lee, Mojica, and Lovett (2020) investigated how an online MOOC-Ed, *Teaching Statistics with Data Investigations* (TSDI), impacted teachers' beliefs about teaching statistics. The course offered several SDL opportunities, including statistics tasks by grade level to enhance participant engagement and additional resources and materials termed *extensions* that teachers could access and implement in their practice.

Self-Directed Informal Online Teacher Professional Development

Informal teacher learning can occur through different online platforms, including social media (e.g., Facebook, Twitter), blogs, wikis, and web-based spaces. Teacher learning has been studied in several ways in these more casual learning environments. Earlier research on using Facebook as a source for learning has focused on college and university students (Hew, 2011; Junco, 2012; Kirschner & Karpinski, 2010; Ranieri, Manca & Fini, 2012; Shih, 2011).

In the past, researchers have agreed there have been limited empirical research studies on Facebook as a potential PD tool for teachers (Bissessar, 2014; Ranieri et al., 2012), prompting them to conduct studies on the value of social networks as spaces for teacher learning. However, there is an increase in research on informal learning environments as spaces for teacher learning opportunities (Lantz-Andersson, Lundin, & Selwyn, 2018; van Bommel, Randahl, Liljekvist, & Ruthven, 2020). More recently, Anderson (2018) conducted a revelatory case study and collected the posts, comments, and responses of a public Facebook group forum supporting mathematics teachers. Findings indicated four distinct patterns of interactions: providing desired help, reframing help, challenging help, and collaborative help. Anderson concluded that these interactions allowed for professional learning. The empirical evidence confirms the notion that informal discourse communities were developed and sustained through teachers' own initiatives in actively pursuing support(s) from others and reflecting on the usefulness of comments to influence future activities. Facebook as a medium for SDL gives the learner freedom to define what is worth learning, and discourse engagement constitutes teacher facilitation of learning (Loeng, 2020).

Recently, several studies have researched the utility of networks in social media. Bissessar (2014) interviewed administrators and members of a Trinidadian Facebook site with 4,895 active members. The author found the platform was a source of sustained intensive PD relating to classroom practices driven by members collectively sharing knowledge and practices. Similarly, van Bommel et al., (2020) recognized the importance of social networks in supporting teachers' collective knowledge. Van Bommel and colleagues conducted an instrumental case study on six Facebook groups in Sweden to ascertain how teachers built professional knowledge across discussions. The study analyzed discussion threads and found that 86% of threads included knowledge-building content, while 11% of threads indicated teachers' transformations (new understanding) in knowledge.

Researchers have also studied Twitter as a space for online teacher learning (Carpenter & Morrison, 2018; Rehm & Notten, 2016; Wesely, 2013). Risser (2013) employed a mixed methods approach to analyzing interactions and mapping the mentoring network of a single novice teacher's Twitter community used as a professional mentoring space. The most common interactions were the novice teacher's request for information, followed by responding to others. The study concluded the content of tweets was influenced by the teacher's characteristics (i.e., experience). In similar findings examining tweets, Forte, Humphreys, and Park (2012) found that experienced teachers needed less support and had more resources accessible to them. In contrast, novice teachers have more questions and few resources.

Davis (2015) interviewed nineteen teachers across the United States to garner teacher perceptions of Twitter for PD in an embedded case study. Findings related to teacher learning indicated all participants valued the space for sharing knowledge and resources, including best practices. Teachers also expressed the importance of creating a community of inquiry where collaborative discussions supported their teaching instead of traditional consumer-based PDs. Another interesting theme was that all participants viewed the online forum as meaningful for reflective thinking and empowered them to choose when they contributed to discussions and to what extent. Concerning choice, Loeng (2020) notes that SDL empowers learners to identify and recognize their choices to engage with others. These studies point to self-directed teacher learning in online spaces as legitimate learning opportunities. Many studies included self-reported data, so future studies should seek to research the impact of oTPD on teaching practices through in-depth interviews and observations to determine the influence of their learning on student outcomes (Hollebrands & Lee, 2020; Macià & García, 2016).

MOOC-Ed Discussion Forums-An Informal Learning Space

As online learning opportunities continue to transform K-12 and higher education teacher experiences; mathematics teachers have been provided with diverse digital resources to support their professional development (Boris, Campbell, Cavanagh, Petocz, & Kelly, 2013). Massive Open Online Courses for Educators (MOOC-Eds) provide professional development opportunities for teachers, and these courses have the potential to impact teacher practice (Yuan & Powell, 2013). Many studies suggest that teacher practice is influenced when professional development is accessible, content-focused, collaborative, involves active learning experiences, and uses models and modeling (Darling-Hammond, Hyler, & Gardner, 2017; Herrington, Herrington, Hoban, & Reid, 2009; Luebeck, Roscoe, Cobbs, Diemert, & Scott, 2017; Vrasidas & Zembylas, 2004). In these professional development courses, educators often engage in online discussion forums as one of several course components that promote learning in collaborative online communities (Wen, Yang, & Rose, 2014).

Discussion forums play an integral role in most MOOC courses and are used by facilitators to accomplish diverse expectations for MOOC participants (Cohen, Shimony, Nachmias, & Soffer, 2019). These forums have the potential to increase engagement, stimulate participants' motivation, support active learning through the co-construction of knowledge, and decrease high attrition rates (Thomas, 2002). These are essential aspects of a practical MOOC pedagogical approach due to the enormous number of participants and few instructors (Onah, Sinclair, & Boyatt, 2014).

Researchers and educators report that information sharing, and interpersonal communication are necessary components for online discussion-based learning (Siemens, 2005; Wise, Cui, Jin & Vytasek, 2017; Yuan, Powell, & Olivier, 2014). However, research also suggests that many online discussions fail to provide rich knowledge construction and enhanced learning experiences that promote elevated levels of thinking (Ertmer et al., 2011; Gao, Zhang, & Franklin, 2013; Kanuka & Anderson, 1998; Marra, Moore, & Klimczak, 2004). Also, many registered course participants choose not to post to discussion forums and take advantage of this constructivist approach to learning (Cohen et al., 2019). Some early studies that have been conducted on the effectiveness of discussion forums in online learning environments found that instead of these spaces increasing engagement and motivation, participants may initially resist this method of engagement (Onah et al., 2014; Thomas, 2002). Although there may be some resistance to this mode of learning, online discussions provide a medium for group interaction and opportunities to gain and share knowledge, as well as discuss teaching practices and ideas (Christensen & Park, 2012; Swan, 2002). According to McLoughlin and Mynard (2009), online discussion forums have the potential to promote meaningful discourse among participants. However, just giving prompts to participants does not automatically lead them to higher levels of knowledge construction. Several studies have used Blooms taxonomy as a tool to measure the level of participant engagement in forums. Garrison, Anderson, and Archer (2001) found that 80% of posts were at the lower level of the higher order thinking scale, and Gilbert and Dabbagh (2005) found that 75-80% of student posts were at the knowledge, comprehension, application stage of Bloom's taxonomy. Presently, there is a limited body of knowledge on how participant interactions occur in MOOC-Ed environments and whether these learning experiences provide rich opportunities for educators' professional growth (Conole, 2015; Cohen et al., 2019). This study examined how the Teaching Mathematics with Technology (*TMT*) MOOC-Ed learning community at a large research university in the southeastern United States experienced learning in discussion forums using the productive online discussion model.

MOOC Discussion Forum Participation

Several studies have shown that discussion forum engagement in MOOCs is low (Brinton, Chiang, Jain, Lam, Liu, & Wong, 2014; Onah et al., 2014). Moreover, Onah et al. (2014) found that forum interactions between participants declined as the MOOC course continued and that interventions such as tutor-moderators had a negative impact on participant discussions while peer support was not an adequate support strategy. MOOC participants who complete courses are likely to have more discussion forum postings than those who do not complete the course (Kizilec, Piech, & Schneider, 2013). Furthermore, several studies have concluded that forum postings are a good indicator of student engagement (Brinton et al., 2014; Coetzee, Fox, Hearst, & Hartmann, 2014; Deng & Tavares, 2013; McGuire, 2013). Arnold and Pistilli (2012) stated that MOOC courses have primary indicators, such as discussion forums, which should be tailored and have adaptive interventions to increase course completion. In addition, Cisel (2014) found that timely feedback from MOOC facilitators may encourage consistent participation and frequent postings in discussion forums. The study also found that active participation in forums was directly associated with achievement and strongly predicted course completion. These studies highlight the critical role that participation in MOOC forums has on learning experiences in online environments.

Content Analysis of Online Discussion Forums

The emerging interest in evaluating online learning environments, including discussion forum postings, has compelled researchers to develop methods and frameworks to analyze the quality of learning. Henri (1992) developed a framework that could be employed by educators to analyze computer-mediated conferencing (CMC) messages. This model focused on five elements of learning (1) participation, (2) interaction, (3) social, (4) cognitive, and (5) metacognitive. Hara, Bonk, and Angeli (2000) analyzed online discussion content using this framework in a traditional classroom setting that included asynchronous online discussions. The study found that student postings were lengthy and included cognitive rigor, like inferencing and reflections on learning experiences. Discussion postings also referenced peers' postings and in-class discussions to build collective knowledge, and postings became more interactive as the course progressed. Cohen, Shimony, Nachmias, and Soffer (2019) conducted a content analysis of a Coursera MOOC-Ed course using the Henri model and found that the content discussed the course topics at the cognitive level "statements exhibiting knowledge and skills related to the learning process" (Henri, 1992, p. 125). Gunawardena, Lowe, & Anderson's (1997) interaction analysis model varied from Henri's (1992) model and focused on the co-construction of knowledge from a social perspective. This model emphasized five phases of knowledge construction through social interaction. The model elements examined sharing information, inconsistencies of shared ideas, negotiations of meaning and synthesis of knowledge, modification of knowledge construction, and agreement and applications of this new knowledge. Several studies have adopted this framework in recent research involving MOOC discussion forum interactions. Gao (2014) analyzed asynchronous online discussions in a graduate-level educational psychology course and found that implementing the interaction analysis model as a strategy to foster meaningful participant interactions improved the quality of discussion between students. Kellogg, Booth, and Oliver (2014) studied the patterns of peer interactions in two MOOC-Ed courses offered to elementary through middle grades teachers and school and district leaders, respectively. Applying the interaction analysis model to assess the co-construction of knowledge, the study found that most postings moved beyond sharing information and ideas (phase 1) and agreement (phase 2) to co-construction and synthesis of knowledge (phase 3). However, few posts moved beyond the third phase into modifying newfound knowledge and agreement on applying this knowledge. This difficulty in using discussion forums for effectively promoting deeper learning in social interactions has been documented by several researchers (Aviv, Erlich, Ravid, & Geva, 2003; Hou & Wu, 2011; Pena-Shaff & Nicholls, 2004). Garrison and Archer (2000) designed a conceptual framework termed the practical inquiry model (PIM) to study the cognitive presence of a community of learners. The researchers defined cognitive presence as "the extent to which learners can construct and confirm meaning through sustained reflection and discourse in a critical community of inquiry" (p. 11). The model has four phases, and each phase contains a descriptor (1) triggering events-evocative, (2) exploration- inquisitive,

(3) integration-tentative, and (4)-resolution-committed. Each descriptor has several indicators and a sociocognitive process for each indicator. Subsequently, they used the model as an evaluation tool for two graduate-level online courses by focusing on computer-mediated communication (CMC) termed messages. The study reported that the highest frequency of postings was coded in the exploration phase due to a focus on sharing and comparisons. The integration and resolution phases had the lowest frequencies. They concluded that the low frequencies might have been attributed to instructional design or the lack of an effective computer-facilitated format to support student learning. The practical inquiry model (PIM) has been used extensively in researching student online discourse and shared learning communities (Kanuka & Garrison, 2004; Marra et al., 2004; Liu & Yang, 2012; Stein et al., 2007; Garrison, 2007; Sadaf & Olesova, 2017; Swan & Ice, 2010). These evaluation studies utilized online discussion analysis frameworks from single-dimensional perspectives. The findings are mixed, and further work is needed using a multidimensional approach to gain a deeper understanding of social interactions in asynchronous online settings. This study highlights the importance of purposeful examination of interactions and will provide insight into improving future instruction and course design.

THEORETICAL PERSPECTIVES AND FRAMEWORK

Technological Pedagogical Content Knowledge (TPACK)

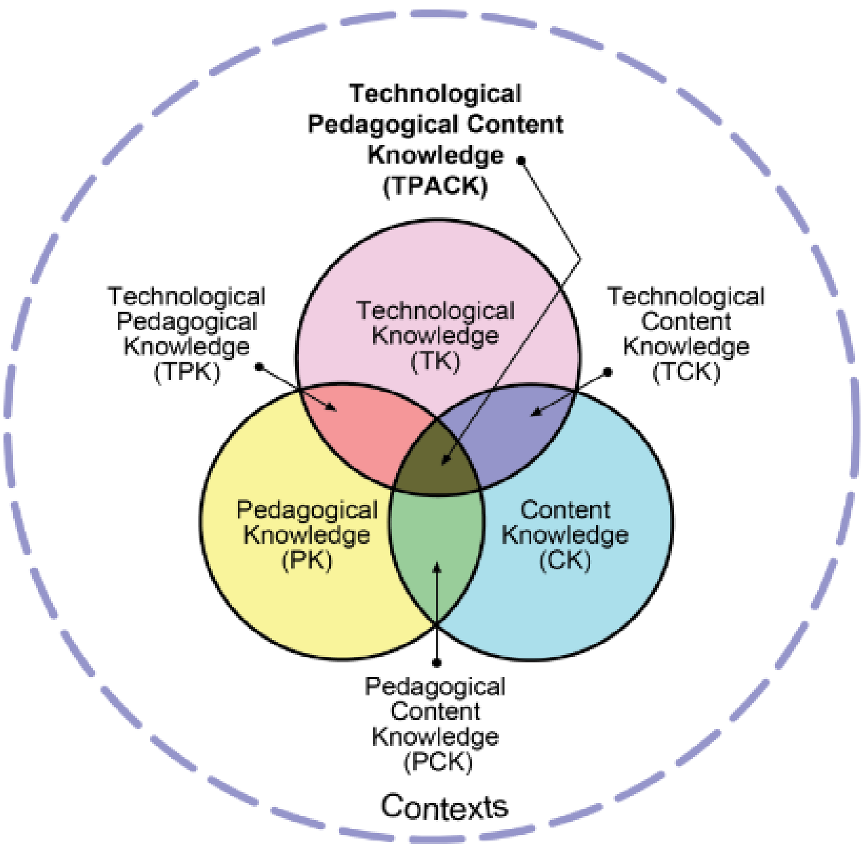
Historically, knowledge in teacher education has solely focused on content, with a more recent shift in teacher education research on pedagogical knowledge and classroom practices (Ball & McDiarmid, 1989; Mishra & Koehler, 2006; Shulman, 1986; Veal & MaKinster, 1999). Before Shulman's (1986) pedagogical content knowledge (PCK) framework, different approaches to research in this area had given attention to either content knowledge or pedagogical knowledge (Ball & McDiarmid, 1989; Shulman, 1987). With an emphasis on content, Shulman proposed three components of content knowledge: 1) subject matter knowledge, 2) pedagogical content knowledge, and 3) curricular knowledge. According to Mishra and Koehler (2006), Shulman was concerned about the mutually exclusive treatment of content knowledge and pedagogical knowledge in teacher education programs and the dichotomy of their relationship being reconciled through the introduction of the PCK framework.

In their seminal piece, *Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge* (2006), Mishra and Koehler extended Shulman's (1986) work and offered a framework to describe the kinds of knowledge teachers should know for effective technology integration in the classroom. Mishra and Koehler (2006) offered teacher knowledge as extremely complex, and any representation of this knowledge should consider the socially constructed and dynamic nature of interconnected relationships between content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK).

The TPACK framework is categorized as the overlapping of CK, PK, and TK to form three specialized knowledge domains: 1) pedagogical content knowledge (PCK), 2) technological content knowledge (TCK), and 3) technological pedagogical knowledge (TPK). Finally, the most sophisticated technology knowledge level is the intersection of the three domains forming technological pedagogical content knowledge (TPACK). Recently, Mishra (2019) proposed that the outer dotted circle be understood as contextual knowledge (XK). He offered that distinct types of teacher knowledge for successful technology integration in education are enhanced by filling the unenclosed space around full knowledge spaces with XK (i.e., district, state, or national policies, awareness of technologies) to "maintaining semantic consistency" (Mishra, p.76). More importantly, XK is a domain that teachers can operate within, change, and help educators foster.

Figure 2.1

TPACK Framework. Reproduced by permission of http://tpack.org



Content knowledge refers to the specific subject matter to be taught and learned in a course (Koehler & Mishra, 2009; Mishra & Koehler, 2006). Content knowledge deals with the facts, theories, and concepts within a given discipline, how ideas connect across the domain, and how content relates to other fields (Mishra & Koehler, 2006). For example, mathematics teachers should understand the theoretical proof of the Pythagorean theorem and the practical implications of the theorem in a specific context (e.g., structural engineering). Pedagogical knowledge involves the processes and methods of teaching and learning. This knowledge can involve lesson planning and implementation, using instructional strategies, student assessment practices, and classroom management (Angeli & Valanides, 2005; Koehler & Mishra, 2009; Koehler, Mishra, Kereluik, Shin, & Graham, 2014; Margerum-Leys & Marx, 2002). Technology knowledge encompasses knowledge about traditional and newer technologies that can be integrated into the class curriculum (Koehler & Mishra, 2009; Koehler et al., 2014; Mishra & Koehler, 2006). Technologies may comprise various instruments, including textbooks and whiteboards to more advanced technologies like web 2.0 tools, 3-D printers, and software programs. Included in this knowledge domain are the necessary skills and abilities needed to learn and adapt to new and emergent technologies (Mishra & Koehler, 2006).

Situated Learning using TPACK

Mishra and Koehler (2006) put forth that the TPACK framework was developed based on situated cognition theory. Brown, Collins, and Duguid (1989) contributed that situated cognition holds the theoretical perspective that “knowledge is situated being in part a product of the activity, context, and culture, in which it is developed and used” (p. 1). The fundamental theoretical view of situated learning is closely aligned with the aim of the TPACK framework. Collins (1988) delineated situated learning as contextualized learning of knowledge and skills in a way that will apply to real life. Several features of situated cognition theory and the concept of situated learning provide insight into how teachers develop TPACK knowledge (Greeno, 1998; Voogt, Fissure, Tondeur, & van Braak, 2016). From a social perspective, Brown et al. (1989) emphasized the notion of *cognitive apprenticeship,* where learning is supported through social interaction and the acquisition, use, and refinement of cognitive tools in authentic contextual activities. Another critical aspect of learning from a situated perspective is *communities of practice* (CoP). Wenger (2011) defines CoP as “groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly” (p. 1). Lave and Wenger (1991) argued that social interaction and collaboration are necessary learning elements through a community of practice. In developing an understanding of teacher knowledge using TPACK, Voogt et al. (2016) suggests teachers' knowledge develops through actively constructing their formal knowledge using experiences in practice while practical knowledge develops through interactions in social subsystems (i.e., students or colleagues). The next section will discuss two mathematics education articles and how the TPACK framework has guided each study.

TPACK as a Framework for Research

The popularity of TPACK as a framework for research and evaluation studies has increased in K12 and higher education to include online teaching and learning, the use of internet resources, and course development (Abbitt, 2011). Specific to using TPACK in distance education, Archambault (2008) posited that the extent of technology implementation, distinct online pedagogy (i.e., teaching strategies, student outcomes), and instructional design principles should be considered when creating online courses.

As early as 2005, Mishra and Koehler developed a quantitative survey instrument that measured faculty members' perceptions and master students using the 'learning by design' approach to developing online courses using TPACK as a framework. Since then, TPACK has informed the design of online learning environments to include preservice education courses and professional development in numerous empirical studies (Brinkley-Etzkorn, 2018; Doering, Valetsianos, Scharber, & Miller, 2009; Herring, Meacham, & Mourlam, 2016; Koehler, Mishra, & Yahya, 2007; Önal, 2016; Voogt et al., 2016). In a more recent study, Niess and Roschelle (2018) analyzed the impact of a four-course online TPACK-based graduate program to train in-service teachers with an online TPACK learning trajectory. The learner-centered program emphasized knowledge-building communities and reflection on teaching experiences. Findings indicated that teachers experienced a deeper understanding of TPACK and shifted towards student-centered instructional approaches. TPACK has been used as a theoretical guide to develop online instructional competency with higher education faculty outside of teacher education (Alsofyani, bin Aris, & Eynon, 2013; Arinto, 2013; Herring et al., 2016; Scott, 2009). TPACK has also provided a lens to evaluate the quality of tasks in online courses (Oster-Levinz & Klieger, 2010) and the pedagogical strategies high school teachers used while designing and implementing web-based lessons (Valtonen, Kukkonen, & Wulff, 2006). As mentioned earlier, the theoretical underpinnings for TPACK support learner-centered pedagogical strategies, including shared communities of practices where participants interact and learn together while developing and sharing resources. Finally, several studies have used the TPACK to develop and evaluate communities of practice to understand better the dynamic relationships between collaboration, communication, and learner satisfaction within online learning environments (Bostancioglu, 2018; Fessakis, Theodoridou, & Roussou, 2014; Jang & Chen, 2010).

Archambault (2008) stated that the TPACK "involves an understanding of the complexity of the relationships among students, teachers, content, technologies, practices, and tools; it is ideal for conceptualizing many of the characteristics that comprise successful online teaching" (p. 5). Given the affordances technology provides in mitigating factors that impact learning in distance education, Archambault contends that greater emphasis should be placed on how technology knowledge is situated with content knowledge and pedagogical knowledge in teacher learning.

TPACK in Mathematics Education

Mishra and Koehler (2006) outline the TPACK framework "can be used to design pedagogical strategies and an analytic lens to study changes in educators' knowledge about successful teaching with technology" (p. 1046). Niess, van Zee, and Gillow-Wiles (2010) conducted an interpretive case study in an online graduate course with twelve K-8 in-service mathematics and science teachers. The course objective was to develop teacher knowledge on integrating spreadsheets as a learning tool, while the study aimed to examine teachers' PCK to TPACK pathway. More specifically, the study examined the course's impact on teachers' perceptions of teaching with spreadsheets and types of knowledge specific to spreadsheets. Data was collected from one teaching observation using the Reformed Teaching Observation Protocol (RTOP), course assignments, online discussion forums, and interview transcripts. Teacher observations were coded using TPACK level descriptors (Niess et al., 2009), and course assignments, forums, and interview transcripts were coded using whole-to-part inductive analysis on course assignments. Initially, the TPACK levels for all participants at the onset of the study were identified as *recognizing*. After the course, eight of the twelve teachers identified at the *accepting* level, two were at the *adapting* level, and two were at the *exploring* level. All teachers experienced a significant increase in TPACK self-efficacy, indicated by changes in TPACK levels.

Özgün, Meagher, and Edwards (2010) conducted a study of twenty preservice teachers in a mathematics teaching methods course. Data was compiled from several sources, including a pre-post mathematics technology attitudes survey (MTAS), three intermediate surveys, an open-ended survey at the end of the course, and field experience reports. The instructor modeled learning activities using technology tools emphasized technological pedagogical knowledge (TPK). Students completed pedagogical tasks (lesson plans, calculator activities), analyzed student work for accuracy, developed two technology lessons, designed five mathematics activities for the TI-Nspire, and researched teaching mathematics problems with the graphing calculator. Findings pointed to changes in how students' understood technology as a tool for reinforcement to use technology to assist students in developing a deeper conceptual understanding of mathematics. Equally important, students also experienced a shift in their identity from mathematics learners to mathematics teachers.

Beginning Mathematics Teachers Technology Use

Teachers' decisions when using technology in their practices are influenced by the knowledge acquired in teacher preparation programs (Lee & Hollebrands, 2008). Niess (2005) reported that teacher preparation programs are evolving in their approach to integrating technology into teacher training for novice teachers. Traditionally, teacher preparation programs provided a single course on technology integration separate from pedagogical coursework. More recently, there has been a shift to emphasize technology with an integrated approach that supports pedagogical content knowledge (Niess, 2005). Specific to mathematics, Common Core State Standards for Mathematics (CCSSM) highlight the use of technology tools as essential to driving curriculum reform and student learning in the classroom (NGA Center, 2010). The Association of Mathematics Teacher Educators (AMTE, 2006) recommends that preservice and early teachers are afforded opportunities to acquire the skills and knowledge needed in mathematics teacher preparation programs to incorporate technology in their classroom teaching practices.

The TPACK framework provides affordances and constraints demonstrating its applicability to varying contexts, including preparing preservice and beginning mathematics teachers to incorporate technology into their practices. Subsequently, the TPACK as a conceptual framework for studying preservice and in-service teacher learning and training in educational contexts has been more widely accepted in educational and research communities (Joo, Park, & Lim, 2018; Okumus, Lewis, Wiebe, & Hollebrands, 2016).

Scherer, Siddiq, and Tondeur (2019) reported that TPACK includes the types of specialized knowledge about teaching and learning with technology educators should have to integrate technology in meaningful ways. They pose the TPACK model,

> emphasizes the importance of preparing preservice teachers to make sensible choices in their uses of technology when teaching content to a specific target group, as it can lead to a better understanding of how teachers make decisions that affect technology acceptance and integration into teaching and learning processes (p. 14).

In previous years, several research studies supported the notion that TPACK was ambiguous and lacked clarity on how the intersectional constructs of PCK, TCK, TPK, and TPACK relate to each other (Cox and Graham, 2009; Graham, 2011; Ruthven, 2014). Lee and Hollebrands (2008) mentioned the difficulty in measuring prospective teachers' TPACK beyond assessing the components of TPACK individually. To further acceptance in the mathematics education research community, Zelkowski, Gleason, Cox, and Bismarck (2013) developed and validated a 22-question TPACK instrument to measure TPACK for preservice secondary mathematics teachers. Although isolating PCK, TCK, and TPK was a limitation of the study, the instrument validated the interrelated components of teachers' knowledge in integrating technology.

More recently, the second-level constructs (TPK, TCK, PCK) of TPACK have received more attention, and the relationships between knowledge domains (Celik, Sahin, & Akturk, 2014; Pamuk, Ergun, Cakir, Yilmaz, & Ayas, 2015; Patahuddin, Lowrie, & Dalgarno, 2016). More recent research points to the TPACK framework as a more robust model for teachers' technology integration practices in education. Mei, Brown, and Teo (2018) found that teachers that reported strong self-efficacy in the TPACK domains were more confident in integrating technology into their teaching practices. Hsu (2016) concluded that perceived ease of use and perceived usefulness could be determined using TPACK. Joo, Park, and Lim (2018) argued that preservice teachers' TPACK impacted their self-efficacy and perceived ease of technology use. With these findings, TPACK is a suitable framework for studying teaching and learning when considering beginning and in-service teachers' use of technology to facilitate student learning. The next section will briefly discuss how TPACK has been applied to guide research and development efforts in distance education.

TPACK As a Framework for Evaluating Online and Blended Teacher Learning

Online and blended learning settings termed 'distance education' provide legitimate educational opportunities for professional learning (Niess & Roschelle, 2018). Distance education is defined as "institution-based, formal education where the learning group is separated and where interactive telecommunications systems are used to connect learners, resources, and instructors" (Schlosser & Simonson, 2009, p. 1). The TPACK or framework elements have been applied independently or combined with other models to study various phenomena in distance education research.

The popularity of TPACK as a framework for research and evaluation studies has increased in K12 and higher education to include online teaching and learning, the use of internet resources, and course development (Abbitt, 2011). Specific to using TPACK in distance education, Archambault (2008) posited that the extent of technology implementation, distinct online pedagogy (i.e., teaching strategies, student outcomes), and instructional design principles should be considered when creating online courses.

TPACK has been used as a theoretical guide to develop online instructional competency with higher education faculty outside of teacher education (Alsofyani, bin Aris, & Eynon, 2013; Arinto, 2013; Herring et al., 2016; Scott, 2009). Archambault (2008) stated that the TPACK "involves an understanding of the complexity of the relationships among students, teachers, content, technologies, practices, and tools; it is ideal for conceptualizing many of the characteristics that comprise successful online teaching" (p. 5). Given the affordances technology provides in mitigating factors that impact learning in distance education, Archambault contends that greater emphasis should be placed on how technology knowledge is situated with content knowledge and pedagogical knowledge in teacher learning.

TPACK Research in K-16 and Higher Education

Several studies have emphasized the need to develop TPACK in preservice teachers, practicing teachers, and higher education. Mouza, Karchmer-Klein, Nandakumar, Ozden, and Ku (2014) conducted a study to advance a pedagogical approach that aimed to support preservice teachers' technology integration and the impact on participants' TPACK knowledge and teaching practices. TPACK surveys were analyzed using repeated measures *t*-testing and case reports were analyzed using inductive approaches. Results showed significant gains in all seven TPACK constructs and effect sizes that ranged from medium to large. In an exploratory study, Abbitt (2011) investigated the relationship between the self-efficacy beliefs of preservice teachers technology integration and their perceived TPACK knowledge. Multiple regression analysis of 47 question pre-test and post-test results revealed a change in the relationship between preservice teachers self-efficacy beliefs and their knowledge in the TPACK domains. Erdogan and Sahin (2010) analyzed the relationship between preservice teachers TPACK and their achievement levels (i.e., GPA). Independent *t*-testing was conducted based on the departmental affiliation (elementary mathematics education and secondary mathematics education) of students. Findings indicated elementary math education majors reported higher levels of TPACK knowledge due to taking more courses in in technology and pedagogy. Additionally, it was found that GPA scores are a strong predictor of TPACK knowledge as evidence by higher self-efficacy scores. In a quasi-experimental study, Tokmak, Ogelen, and Incikabi (2013) investigated the change in TPACK for 31 mathematics pre-service teachers who were enrolled in a computer technology course designed with TPACK based activities. Data was collected using a TPACK self-efficacy Likert survey and analyzed using paired sample *t*-testing. Results indicated significant differences between pre- and post- TPACK scores in preservice teachers TPACK self-efficacy.

Hill and Uribe-Florez (2020) explored the TPACK of middle and high school math teachers and to what extent the teachers integrated technology in the mathematics classroom. The concurrent mixed-methods study employed the Zelkowski et al. (2013) survey to measure teachers' TPACK and open-ended questions focused on technology integration. Data was collected and analyzed on thirty-one grades 6-12 mathematics and special education teachers. The study found that teachers reported the lowest scores in technology knowledge while pedagogical knowledge had the highest average scores followed by content knowledge. In a quasi-experimental study, Njiku, Mutarutinya, and Maniraho (2021) conducted mathematics teachers professional development that incorporated collaborative TPACK-designed learning activities focused on strengthening teachers' TPACK in designing lessons and implementation. The design included a control group that did not participate in professional development activities and two experimental groups. The authors used paired sample *t*-testing to analyze pre- and post- TPACK survey results of 125 secondary school mathematics teachers. Results showed that all three groups difference in scores were statistically significant. However, the experimental groups had larger effect sizes than the control group. A second round of quantitative testing using a split-plot analysis of variance determined that the changes in TPACK participant scores was directly influenced by the professional development activities.

Stover and Veres (2013) conducted research using the TPACK as a framework in higher education to ascertain participant learning in each TPACK knowledge domain in an online instructional design course at a public university. Eleven graduate students completed self-reported TPACK surveys before and after the course ended. Using paired sample *t*-testing, results indicated an overall improvement in graduate students TPACK learning. Analysis also showed that participants showed less change in individual constructs of technological knowledge, pedagogical knowledge, and content knowledge. Brinkley-Etzkorn (2018) conducted a concurrent embedded mixed methods study on 92 university instructors after faculty development training using TPACK as a conceptual framework to measure their teaching effectiveness and knowledge integration. Data was collected from course syllabi, student evaluations of teaching scores (SETS), and a self-reported online teaching skills inventory. Results showed that there were no statistically significant changes in instructors student evaluation scores. It was found that initial SETS scores were relatively high which inhibited significant changes in scores after the intervention. Qualitative findings indicated that instructors viewed TK, PK, and CK as separate learning domains deemphasizing the importance of an integrated approach to professional development. Additionally, educators learn most of their content knowledge prior to the start of teaching in the classroom and begin their careers in synchronous face-to-face settings while pedagogical practices and strengthening technological skills improve after they begin teaching.

Productive Online Discussion Model

Gao, Wang, and Sun (2009) propose a model that identifies four dispositions of productive online discussions and three specific learner actions for each disposition. The four dispositions (see Figure 2.2) are as follows: 1) discuss to comprehend – active engagement in cognitive processes (e.g., interpretation, elaboration, and making connections with prior knowledge); 2) discuss to critique – examination of participant views, and being sensitive and analytical to conflicting views; 3) discuss to construct knowledge – active negotiation of meanings, and being ready to reconsider, refine, and sometimes revise one's thinking; and, 4) discuss to share improved understanding – actively synthesize knowledge and explicitly express improved understanding based on a review of previous discussion. Listed under each disposition are three subcategories (learner actions). This model was developed as a comprehensive framework that considered the singular aspects of three previous frameworks: (a) Henri’s (1992) multi-dimensional model of communication analysis focused on cognitive processes, (b)

Gunawardena, Lowe, & Anderson's (1997) interaction analysis model that explored how knowledge was constructed in social environments and (c) Garrison, Anderson, and Archer's (2001) model of cognitive presence aimed at argumentation and the cognitive processes involved with critical thinking. The productive online discussion model dispositions and learner actions listed in Table 2.1 were employed as the a priori coding frame used for this study (Schreier, 2014; Mayring, 2015) due to the coherent, multi-dimensional synthesis of previous frameworks.

Figure 2.2

The Productive Online Discussion Model (Gao, Wang, & Sun, 2009)

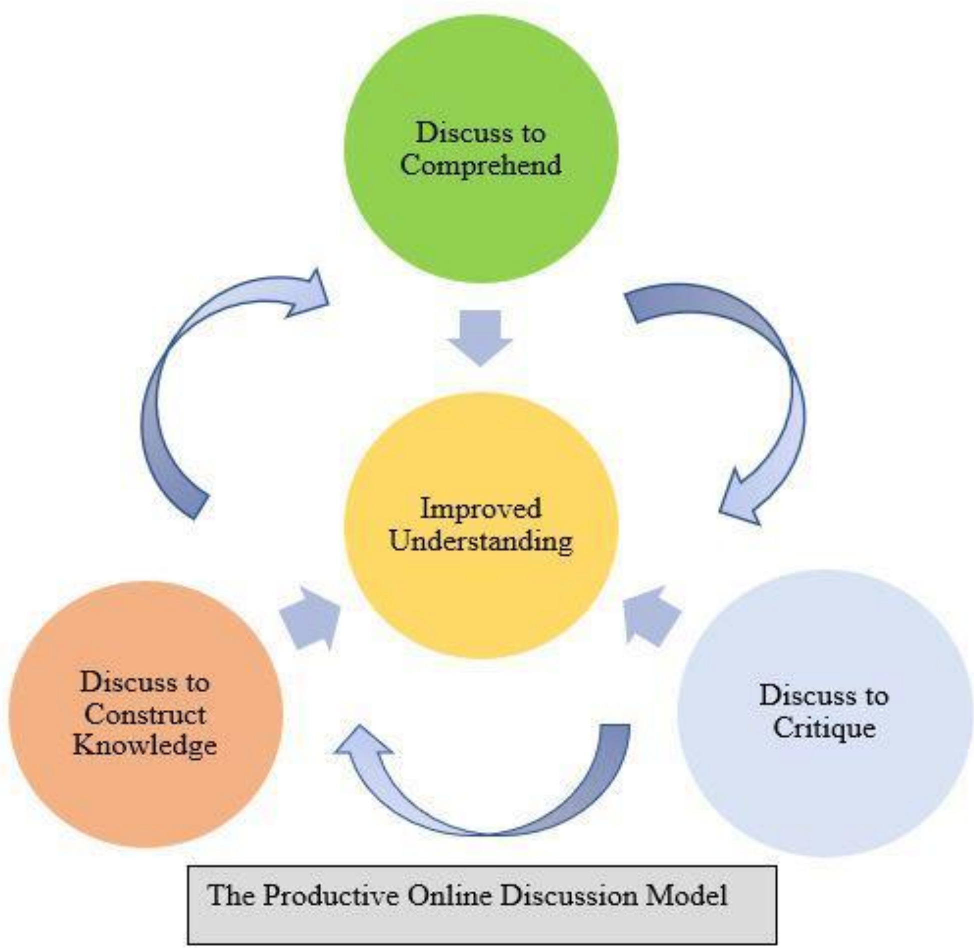


Table 2.1

A Priori Coding Frame for Discussion Forum Content Analysis (Gao, Wang, & Sun, 2009)

Dispositions	**Learner Actions**
1. **Discuss to Comprehend -** Actively engage in such cognitive processes as interpretation, elaboration, and making connections with prior knowledge.	a) Interpreting or elaborating the ideas by making connections to the learning materials. b) Interpreting or elaborating the ideas by making connections to personal experience. c) Interpreting or elaborating the ideas by making connections to other ideas, sources, or references.
2. **Discuss to Critique**: Carefully examine other people's views and be sensitive and analytical to conflicting views.	a) Building or adding new insights or ideas to others' posts. b) Challenging the ideas in the text/MOOC content. c) Challenging the ideas in others' posts
3. **Discuss to Construct Knowledge:** Actively negotiate meanings, and be ready to reconsider, refine and sometimes revise their thinking.	a) Comparing and contrasting views from the text or others' posts. b) Facilitating thinking and discussions by raising questions. c) Refining and revising one's own view based on the texts or others' posts.
4. **Discuss to Share Improved Understanding**: Actively synthesize knowledge and explicitly express improved understanding based on a review of previous discussions.	a) Summarizing the personal learning experiences of online discussions. b) Synthesizing discussion content. c) Generating new topics based on a review of previous discussions.

The TPACK Framework and the Productive Online Discussion Model are used to guide the data collection and analysis of the results in this study. Methodology, including data collection and analysis, will be described further in the next chapter.

CHAPTER 3: METHODS

Research Design

The purpose of this study was to examine the relationship between MOOC-Ed teacher learners involvement in discussion forums and their TPACK. A mixed methods research design was employed that integrated both qualitative and quantitative methods of data collection and analysis. For this study, mixed methods research will be defined as a study that,

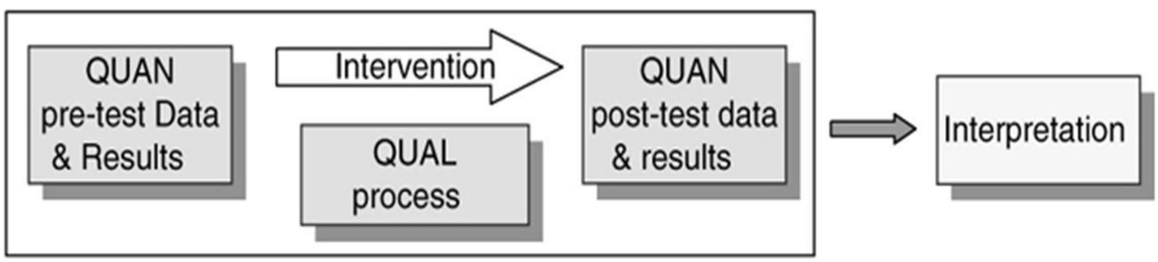
> Involves the collection or analysis of both quantitative and/or qualitative data in a single study in which the data collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research (Clark, Gutmann, & Hanson, 2008 p.165).

A core tenet of this approach to research is that the collection and analysis of qualitative and quantitative data provides a more sophisticated understanding of information beyond what qualitative and quantitative methods provide alone (Creswell & Creswell, 2017).

More specifically, a concurrent embedded mixed methods design (QUAN + QUAL) described in Figure 3.1 was used for this research study. This study is partially mixed concurrent equal status (QUAN+QUAL) that gives equal weight to quantitative and qualitative data (Schoonenboom, & Johnson, 2017). Both quantitative and qualitative data was collected and analyzed separately then the data was mixed for analysis (Leech & Onwuegbuzie, 2009). Quantitative pretest data was collected in the initial stage of the study. The embedded aspect of the study occurs during the intervention stage. At this point in the study qualitative data was collected simultaneously while conducting the research treatment. Following the intervention, quantitative post-test data was collected (Creswell & Creswell, 2017; Edmonds & Kennedy, 2016). The concurrent embedded mixed-methods design is appropriate when the intervention phase occurs between the pre-and post-quantitative stages of the research study (Creswell, 1999). The qualitative phase of research identifies themes and then statistical analysis is conducted to examine research questions and test hypotheses in the quantitative phase (Caracelli & Greene, 1993). This study design aligned with the Teaching Mathematics with Technology (*TMT*) MOOC-Ed analysis of interactions in discussion forums (QUAL), and the results were used to influence the data analysis of self-reported TPACK data (QUAN).

Figure 3.1

Concurrent Embedded Mixed Methods Study Design (Creswell & Plano Clark, 2007; Creswell, Plano Clark, & Garrett, 2008).



Mixed methods research appeared in the early 20th century when it was used to describe multiple forms of fieldwork in the social sciences (e.g., Chapin, 1920) (Creswell, 1999; Clark, Gutmann, & Hanson, 2008). Campbell and Fiske (1959) further developed mixed methods. In their work, Campbell and Fiske emphasized multi-quantitative methods approach to studying personality traits. Sieber (1973) furthered the discussion on the potential for this method of inquiry to integrate research techniques to advance the design, collection, and analysis of data. Subsequently, several others pushed the conversation to include triangulation of data (Jick, 1979), the convergence of findings, and the need for (a) consistency in findings, (b) enhancement of results from different methods, and (c) development one method advancing another method (Rossman & Wilson, 1985, 1994). An increased interest in the purposes and reasons in the design of these types of studies has emerged in recent years (Creswell & Creswell, 2017). In particular, Creswell (1999) contributes three primary reasons to conduct a mixed-methods study:

1. Converging of results from qualitative and quantitative methods combined will yield more and/or better information than a single method alone.
2. Results from qualitative inquiry can be supported by using quantitative methods, or vice versa. For example, the qualitative inquiry could be exploratory and quantitative methods that follow offer insight into explaining the phenomena, and
3. The qualitative phase of research is exploratory due to a lack of literature on the topic under investigation.

In addition to Creswell, Bryman (2006) conducted content analysis on 232 social science articles and offered a series of sixteen distinct justifications for mixed methods research. The following are eight justifications applicable to this current study.

a) *Triangulation*-combining qualitative and quantitative data collection and analysis for the triangulation of findings to substantiate an argument and provide validity.
b) *Offset*-research methods associated with qualitative and quantitative research have their own strengths and weaknesses. Combining approaches counteract the weaknesses of each approach.
c) *Completeness*- involves the assumption that bringing together qualitative and quantitative approaches gives a more comprehensive understanding of the phenomenon being studied.

d) *Process*-quantitative research seeks to confirm or test a theory or hypothesis, and qualitative research seeks to understand experiences.

e) *Explanation*-one approach is used to explain the findings generated by the other.

f) *Sampling*-one approach is used to garner respondents for sampling or cases.

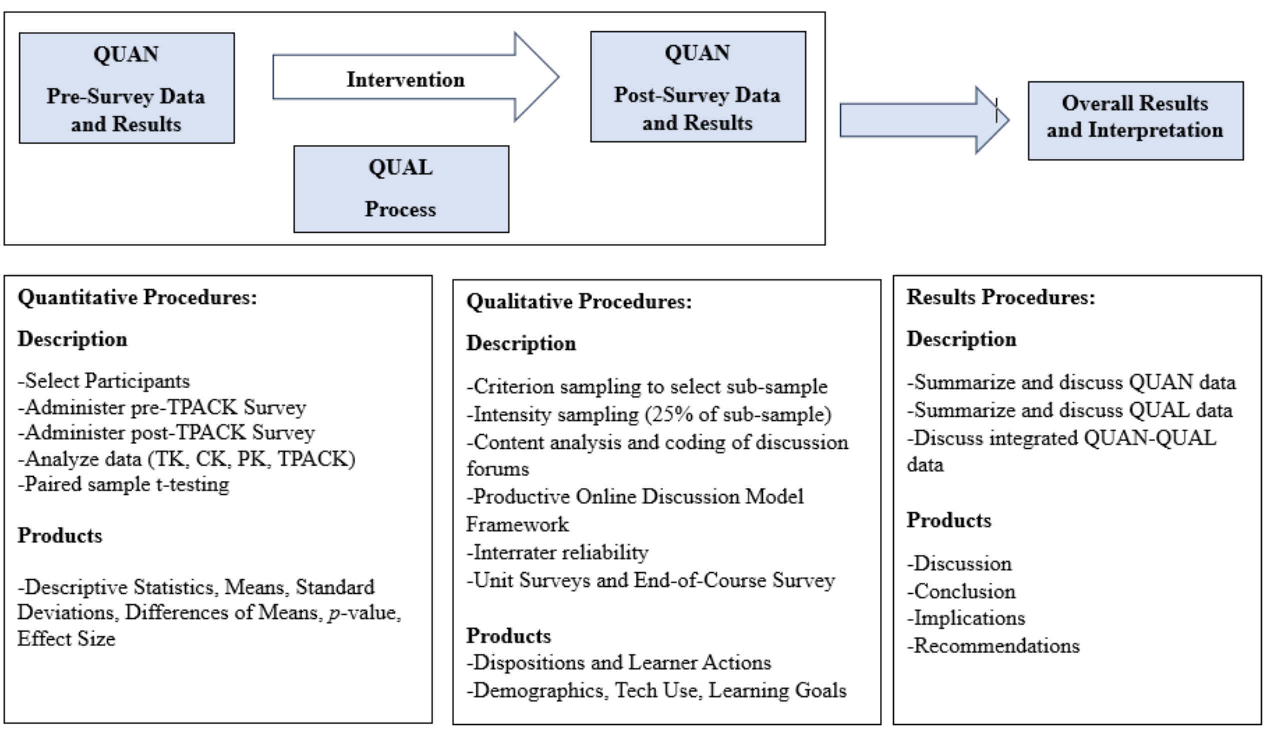
g) *Credibility*-using both approaches add to the fidelity of findings.

h) *Illustration*-employing qualitative data to illustrate quantitative findings.

An organizational model of the methodology for this study is given in Figure 3.2

Figure 3.2

Concurrent Embedded Research Study Design Elements



Description of *Teaching Mathematics with Technology* MOOC-Ed

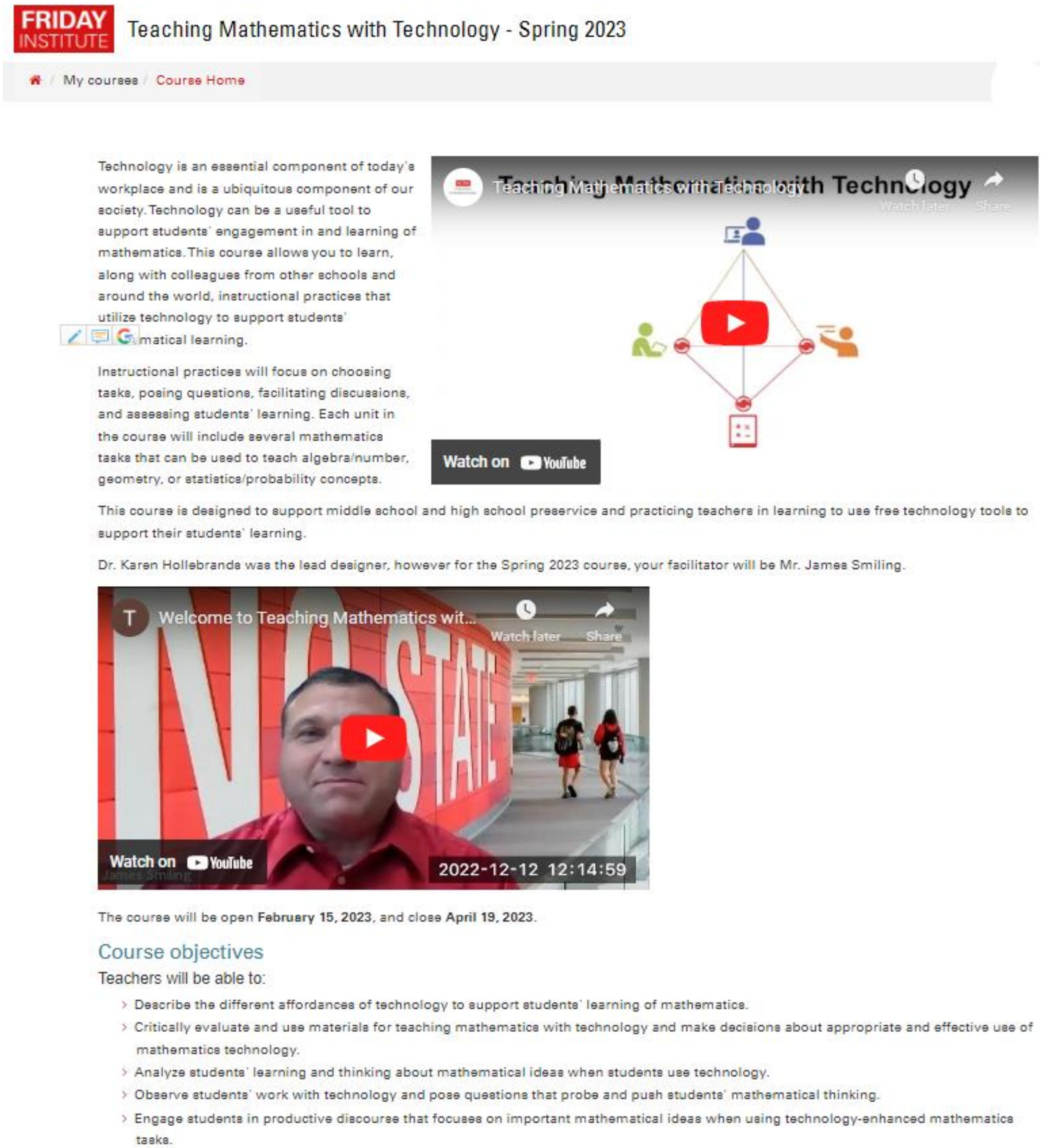
Since Fall 2016, the Friday Institute at NC State University has offered the *Teaching Mathematics with Technology (TMT)* MOOC for Educators (MOOC-Ed) course focused on the teaching and learning of mathematics with technology. The course has been offered six times from Spring 2016 to Spring 2022 with approximately 3600 participants. The course is intentionally designed for middle and high school preservice and practicing teachers. The purpose of the MOOC-Ed is for teachers to learn instructional practices on utilizing technology to support students' learning in mathematics (access https://go.ncsu.edu/tmt).

MOOC-Ed Design Principles. The *TMT* MOOC-Ed includes four key research-based design elements: multiple voices, self-directed learning, peer-supported learning, and job-connected learning (Dede et al., 2016). *Multiple voices* afford participants the opportunity to hear and learn from each other, instructors, researchers, and experts in the field. In addition, *self-directed learning* occurs as participants personalize their experiences and choose what resources and activities they engage with to meet their personal learning goals. *Peer-supported learning* is encouraged through interactions with other participants, reviewing and giving feedback on projects, and any other exchanges within the course. *Job-connected learning* materializes as participants engage in classroom projects and activities aligned to critical problems of frequent practice they encounter in their own classrooms, schools, or districts (Dede et al., 2016).

The *Teaching Mathematics with Technology* course web page (see Figure 3.3) gives teacher learners an introduction and overall description of the course and course objectives. Participants have the option of completing a pre-survey to self-assess their level of comfort using mathematics technology tools and a pre-course TPACK survey. They can also participate in a *meet your colleagues'* discussion forum and record a video introduction using the Flipgrid recording web tool.

Figure 3.3

Teaching Mathematics with Technology MOOC-Ed Introduction and Description, (NCSU Friday Institute, n.d.)



FRIDAY INSTITUTE Teaching Mathematics with Technology - Spring 2023

My courses / Course Home

Technology is an essential component of today's workplace and is a ubiquitous component of our society. Technology can be a useful tool to support students' engagement in and learning of mathematics. This course allows you to learn, along with colleagues from other schools and around the world, instructional practices that utilize technology to support students' mathematical learning.

Instructional practices will focus on choosing tasks, posing questions, facilitating discussions, and assessing students' learning. Each unit in the course will include several mathematics tasks that can be used to teach algebra/number, geometry, or statistics/probability concepts.

This course is designed to support middle school and high school preservice and practicing teachers in learning to use free technology tools to support their students' learning.

Dr. Karen Hollebrands was the lead designer, however for the Spring 2023 course, your facilitator will be Mr. James Smiling.

The course will be open **February 15, 2023**, and close **April 19, 2023**.

Course objectives

Teachers will be able to:

- Describe the different affordances of technology to support students' learning of mathematics.
- Critically evaluate and use materials for teaching mathematics with technology and make decisions about appropriate and effective use of mathematics technology.
- Analyze students' learning and thinking about mathematical ideas when students use technology.
- Observe students' work with technology and pose questions that probe and push students' mathematical thinking.
- Engage students in productive discourse that focuses on important mathematical ideas when using technology-enhanced mathematics tasks.

MOOC-Ed participants working with free, accessible web-based technology tools (Appendix D) was a critical component in supporting teacher learners' engagement in mathematical tasks and activities throughout the course. Among the technology tools available were Desmos, a popular web-based online graphing calculator, and GeoGebra, an integrated dynamic software for multiple mathematics platforms. Both tools have classroom resources like interactive activities and free digital tools (e.g., collaborative whiteboard) for teachers to access for use in their own classroom. The professional learning course also included Google Sheets, an interactive spreadsheet platform for collaboration and sharing. In addition, CODAP and Tuva were two dynamic, interactive data analysis tools teachers accessed. These statistical platforms supported teachers learning through data manipulation and statistical investigations.

The Teaching Mathematics with Technology MOOC-Ed observed for this study was a five-week course offered from January 2023 to March 2023. The MOOC-Ed consisted of five units. Unit one was titled *Affordances of Technology for the Learning and Teaching of Mathematics* and focused on leveraging mathematics technology for classroom instruction to support students' mathematics learning. Unit two, termed *Capitalizing on the Power of Technology* looks at distinct ways in which technology used in the teaching of mathematics is characterized. Participants were introduced to the important metaphors of technology tools as *amplifiers* or *reorganizers* in this unit. Unit three was titled *Interacting with Engaging Mathematics Tasks*. This unit afforded participants the opportunity to engage in high cognitive demand mathematical tasks and manipulate data with statistical software. Finally, an interactive geometry framework is introduced to analyze mathematical tasks. Unit four, specified as *Multiple-Linked Representations,* examines how different mathematical representations support different student approaches to solving tasks. This unit also offers teachers strategies to encourage students' mathematical discourse about mathematics. Unit five had MOOC-Ed participants *Analyzing Students' Mathematical Thinking* in the last unit that integrates the key ideas of the first four units. The primary focus of this unit is for teachers to explore various approaches to examine students' mathematical thinking. Unit five also included discussion spaces for sharing technology-based tasks between colleagues and opportunities for learning reflection.

MOOC-Ed Content. The unit structure (see Figure 3.4) consisted of an introductory video from the MOOC-Ed lead instructor that informed participants of unit topics and goals. Each unit included an expert panel of a MOOC instructor, expert classroom teachers, and mathematics educators. MOOC units involved participants engaging with mathematical tasks and technologies (i.e., CODAP), discussions with colleagues in the forums, and completing tasks teachers could readily implement in their own teaching practice. Each unit also had an open forum for general discussion, an optional weekly virtual meeting chat for instructors and participants, and a unit feedback survey.

Figure 3.4

Structure of Teaching Technology with Mathematics MOOC-Ed Unit

▪ Engage With Essentials and Extend Your Learning
▪ Learn From Experts
▪ Essential Exploration and Explore More Tasks
▪ Penny Circle Discussion
▪ Connect to Practice
▪ Check Your Understanding
▪ Unit Feedback Survey

To register for the course, participants complete a general enrollment survey that includes demographic and background information and intended learning goals. Additionally, participants can provide consent for secondary data to be used in future research studies. The MOOC-Ed resources and materials comprised a diverse collection of resources, including articles, concise reading handouts, expert panel videos, videos of students and teachers engaging in mathematics, mathematical tasks, and interactive tools. In addition, the course also offered an orientation facilitation guide accompanied by unit facilitation guides for participants who wanted to host small group meetings or conduct professional learning communities (e.g., a group of teachers at the same school). As mentioned earlier in chapter 2, the MOOC-Ed design principles had a structured sequence of activities for each unit like cMOOCs, yet participants had the autonomy to access resources that were of interest to them, like xMOOCs. The option to earn a 20-hour certificate of completion was available to participants for meeting seven specific course requirements (e.g., complete pre-assessment, and post to the discussion forum in each unit).

***TMT* MOOC-Ed Discussion Forums.** Discussion forums were included in several places within the Teaching Mathematics with Technology MOOC-Ed. Discussion forum prompts were provided by the MOOC-Ed instructors. These purposefully designed spaces play an essential role in learning in which participants reflected on interactions with materials and resources, shared their thoughts and ideas with their colleagues, and analyzed tasks and videos. The orientation module included a single discussion forum where colleagues introduced themselves to each other. Units one through unit four had two distinct discussion forums in the Essential Exploration (EE) and Connect to Practice (CP) sections, respectively, in each unit (see Appendix C). Participants' engagement in forums was self-directed in that they could create original threads or reply to other user's posts. Unit five included a single discussion forum in the Connect to Practice (CP). This forum was reflective and focused on participation in the MOOC-Ed and how their learning experience will impact their teaching practices in the future.

Study Participants. There was a total of 147 registered MOOC-Ed participants. Of those registered, participants that provided consent for future course research were potential study participants in the qualitative phase of this study (Appendix E). The intended audience for the *Teaching Mathematics with Technology* MOOC-Ed were middle and high school preservice and practicing mathematics teachers and educators. The MOOC enrollment was open to anyone in the United States and internationally who was interested in learning more about supporting students learning in mathematics with technology tools. In addition, this study was open to non-teacher participants (i.e., school administrators) to be included in the sample of research participants (Carney, Brendefur, Thiede, Hughes, & Sutton, 2016).

Data Sources. Multiple sources of qualitative and quantitative data were collected in this study for the purpose of integration to support the research findings (Sandelowski, 2000). Data sources collected for the *TMT* MOOC-Ed included the demographics enrollment survey, discussion forums content, and pre-and-post-TPACK surveys. The need for multiple data sources contributed to understanding the nature of highly active teacher learners' professional development experience.

Table 3.1

Research Questions—Data Collection and Analysis

Research Question	Data Sources	Types of Analysis
What is the nature of highly active teacher learners' modes of discussion within forum discussions in the Teaching Mathematics with Technology MOOC-Ed?	Discussion Forum Content	Qualitative
What effect does participation in the Teaching Mathematics with Technology MOOC-Ed have on highly active teacher learners' TPACK?	Pre-and Post- TPACK Surveys	Quantitative
What is the nature of the relationship between highly active teacher learners' TPACK and their modes of discussion in the Teaching Mathematics with Technology MOOC-Ed?	Discussion Forum Content, Pre-and Post- TPACK Surveys, Unit Feedback Surveys	Qualitative

Enrollment Survey. Demographic and course enrollment information was collected during the participant enrollment for the MOOC-Ed. The data included the organization and type, school affiliation, gender, area of education and grade level specialization, level of education, years of experience, role at the organization, primary goals for enrolling in the MOOC-Ed, technology confidence level, frequency of technology use, and reason for enrolling in the *Teaching Mathematics with Technology* MOOC-Ed. Demographics were used to discover potential relationships between participant characteristics and dispositions and learner actions in discussion forums and provide insight on survey findings.

Discussion Forums. Discussion forum content was initially generated from the forum prompts provided by the MOOC instructors. The discussion forums supported asynchronous interactions between MOOC participants. Additionally, these were spaces to generate knowledge, introduce ideas, and foster a sense of community. Participants also contributed to others learning by asking questions, reflecting, and giving feedback to others. Discussion forum postings were employed in this study as a primary source of data to examine research question one and determine the sample of participants for quantitative data collection.

TPACK Surveys. The 22-question TPACK survey instrument (Appendix B) was applied as a pre-post self-reported assessment. The TPACK was a measure used to explain the distinct types of knowledge domains that teachers should have to support their students' learning of mathematics. The use of the instrument in a pre-post format allowed for examining changes in TPACK knowledge over the course of the MOOC-Ed offering. Participants initially completed the pre-TPACK survey during the orientation unit of the MOOC-Ed and the post-survey was completed in unit five before the end-of-course feedback survey.

TMT MOOC-Ed Demographics

A total of 147 individuals registered for the Teaching Mathematics with Technology (*TMT*) MOOC-Ed from January-February 2023. All registered participants were invited to complete an enrollment survey that included demographic information and professional learning goals. Of the 147 participants who accessed the course, 39 participants completed the research consent form, completed the pre-and post-TPACK surveys and posted to at least one discussion forum in each of units one through four. Tables 3.3 and 3.4 include enrollment data from the 39 registered participants who meet the criterion to be selected for this research study. According to data from the enrollment survey, MOOC-Ed participants were K-12 classroom teachers, college instructors, teacher preparation specialists, curriculum and instructional coaches, researchers, and administrators. Educators that opted to participate in this research study had a wide range of years of experience and educational levels were also diverse with 46% having a 4-year college degree, 44% having a master's or advanced degree, while 2% had a professional degree, and 8% a doctoral degree. There was also a wide range of years of experience in education with a mean of 14.9 years (SD = 9.19). Most participants (69%) were from the United States with 31% of international participants from nine countries in Africa, Asia, and Europe.

Table 3.2

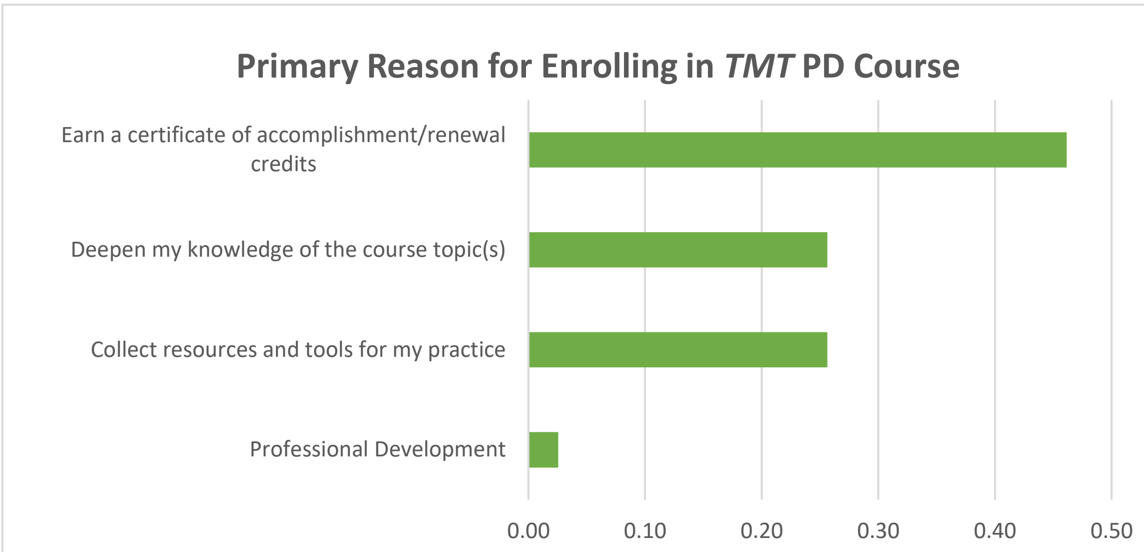
Demographic Profile of TMT MOOC-Ed Research Participants (N=39)

Gender (%)		**Qualifications (%)**		**Years of work experience (%)**	
Female	69	Classroom Teacher	67	0 years	0
Education		**Organization Type**		1-5 years	18
Four-year degree	46	School	64	6-10 years	15
Master’s Degree	44	School District	10	11-15 years	23
Professional	2	College/University	10	16-20 years	18
PhD	8	Other	16	Greater than 20 years	26

Participants chose to enroll in the *Teaching with Mathematics* course for diverse reasons (see Figure 3.5). Forty-six percent stated their primary goal was to earn a certificate or earn continuing education credit while 26% sought to deepen their knowledge of teaching math with technology or access resources and tools that could impact practice. Lastly 3% enrolled for professional development. No research participants chose the options of just browsing, connecting with peers or colleagues, and other.

Figure 3.5

MOOC-Ed Participant Goals (N=39)



Data Collection and Analysis of Research Question 1

Qualitative data were collected and analyzed to examine participants' dispositions and learner actions in discussion forums to address RQ1- What is the nature of highly active teacher learners' modes of discussion within forum discussions in the *Teaching Mathematics with Technology* MOOC-Ed?

Sample Participants and Data Collection. To identify the participants for research question one, *criterion sampling* and *intensity sampling* were adopted as informative strategies (Suri, 2011). Sample participants were chosen in the data collection phase (criterion), and a sub-sample of those participants was selected for data analysis (intensity). The initial sample of participants was chosen based on the consistency of postings. Data was collected from all participants who posted at least once in any discussion forums from unit one to unit four and completed the pre-and post-TPACK survey. The introductions forum and the unit 5 forum content were excluded from data collection and analysis for this study. All discussion forums from units 1 to unit 4 for individual participants were collected for analysis using the following criteria:

(1) participant posted at least one discussion (original thread) or comment (reply to another participant) in the *Essential Exploration* discussion forum, or

(2) participant posted at least one discussion (original thread) or comment (reply to another participant) in the *Connect to Practice* discussion forum.

The rationale for these methodological criteria was situated within the literature on examining highly active discussion forum users in online settings. Wong, Pursell, Divinsky, and Jansen (2015) classified active discussion forum participants as users who contributed an original post or replied to another post in all seven weeks of the MOOC. The authors found that these participants had the highest percentages of posts and were more influential users that impacted overall student engagement. Similarly, Cohen, Shimony, Nachmias, and Soffer (2019) found that learners who were actively posting to forums throughout the entire course had the greatest volume of forum participation, in opposition to users who posted frequently early in the course and their involvement in forums decreased over time.

Intensity sampling was employed as a sampling method to determine the sub-sample of participants' forum postings that would be included in the analysis of research question one. Intensity sampling involves examining significant studies investigating the phenomenon of interest where the study explicates the nature of the success or failure of these cases in a naturalistic way (Patton, 2002; Suri, 2011). Huang, Dasgupta, Ghosh, Manning, and Sanders (2014) studied 44 Coursera MOOC offerings that generated a large corpus (325,071) of forum contributions. Of the 116,028 users who participated in the forums, Huang et al., (2014) considered the top 5% of forum participants to be *super posters.* A smaller study conducted by Dubosson and Emad (2015), researched discussion forum participation in building a sense of community among users in an xMOOC. The authors examined the top ten contributors to the forums in the course. Lastly, Bonafini (2018b) categorized super posters as the top 10% of all forum participants.

Considering the methodologies of the studies' mentioned, criterion sampling was adapted for the *TMT* MOOC-Ed. Given the smaller number of participants in the *TMT* MOOC-Ed and the number of discussion forum postings, the sub-sample of postings for descriptive data analysis initially includes all research participants (n=39) in the study who met the criterion sampling criteria. Additionally, analysis was conducted on the top 25% of all forum contributors who met the inclusion criteria for data collection. These postings were included in the data analysis of research question one to investigate the modes of discussion and the types of dispositions and learner actions taking place in discussion forums for highly active participants.

Data Collection Instrument. The Productive Online Discussion Model (Gao, Wang, & Sun, 2009) was the instrumentation used to address research question one. The model identifies four dispositions of productive online discussions and specific learner actions for each disposition. This framework (see Figure 2.2) can be useful in understanding several types of learning in asynchronous online discussion forums. The four dispositions are as follows: 1) discuss to comprehend – actively engage in cognitive processes such as interpretation, elaboration, and making connections with prior knowledge; 2) discuss to critique – carefully examining other people's views, and be sensitive and analytical to conflicting views; 3) discuss to construct knowledge – actively negotiate meanings, and be ready to reconsider, refine, and sometimes revise their thinking; and, 4) discuss to share improved understanding – actively synthesize knowledge and explicitly express improved understanding based on a review of previous discussion. The four dispositions of the model are described further as specific learner actions as shown in Table 2.1 These dispositions and learner actions were used by the researcher to better understand how participants enrolled in the *Teaching Mathematics with Technology* online course interacted with each other in asynchronous discussion forums.

Data Analysis. The Productive Online Discussion Model was employed as an a priori coding frame to characterize the types of postings that comprised the top 25% of forum postings. A directed content analysis using a deductive approach was suitable based on how contextualized online discussion forums tend to be and use of a defined coding structure (Hseih & Shannon, 2005; Mayring, 2015; Schreier, 2014). Budd, Thorp, and Donohew (1967) define content analysis as “a systematic technique for analyzing message content and message handling” (p. 2). Krippendorff (2018) offers that “content analysis is a research technique for making replicable and valid inferences from texts to the contexts of their use” (p.24). Lastly, Hseih and Shannon (2005) in a salient article titled *Three Approaches to Content Analysis* delineate qualitative content analysis as “a research method for the subjective interpretation of the context of text data through the systematic classification process of coding and identifying themes or patterns” (p. 1278).

In this study, the qualitative content analysis explores patterns and occurrences of learner actions and seeks to establish relationships between dispositions (Gibbs, 2007; Miles & Huberman, 1994). The main categories (dispositions) of the coding frame are unidimensional and the learner actions were mutually exclusive and exhaustive (Schreier, 2014). The discussion forums were analyzed using frequency analysis (Mayring, 2015). The frequency analysis consisted of counting occurrences of dispositions and learner actions in the forum postings and comparing these codes with other occurrences where the categories (dispositions) and subcategories (learner actions) were established prior to analysis.

Coding Process. Both coders (myself and another researcher) had experience on other projects using the productive online discussion model as an a priori coding frame. For this study, each forum was segmented and coded using line-by-line analysis. Subsequently, individual posts could be coded as a single post (i.e., 1c) or allowed for overlapping codes within and across dispositions and learner actions (i.e., 1a, 1b, 2c). The coding team completed two rounds of comparison coding on unit 1 EE and CP forums with an intercoder reliability of .725. The team arbitrated and revised the coding scheme to maintain consistency and reliability in the final iteration of coding. Appendix G includes an excerpt of the forum contributions coded by dispositions and learner actions. The team conducted coding on all discussion forums and arbitration on differing codes was completed for agreement. Intercoder agreeability for coding was calculated at .795 across the four units that were coded. The findings of the frequency analysis provided a platform for further data exploration by examining patterns and simultaneity of trends in specific learner actions (Schreier, 2014). This allowed a deeper dive into the analysis of postings and provided insight into the interactions across dispositions and between the learner actions of the highly active participants (Gibbs, 2007; Miles & Huberman, 1994). Microsoft Excel was used for descriptive data analysis to identify patterns and trends within and across units.

Ethical Statement. This study sought to respect the confidentiality and anonymity of all research participants. Informed consent to use demographic information and course communications for research purposes was provided by MOOC-Ed participants during the registration for the course. All participant names used in this study are fictitious. When coding, the first and last names of participants were hidden to amplify focus on the discussion postings. Having access to participants' names who were enrolled in the course did not influence or bias any aspect of this study.

Data Collection and Analysis of Research Question 2

Quantitative data were collected and analyzed to examine participants' technological pedagogical content knowledge (TPACK) for RQ2- What effect does participation in the *Teaching Mathematics with Technology* MOOC-Ed have on highly active teacher learners' TPACK?

Sample Participants and Data Collection. All participants who registered for the *TMT* MOOC-Ed were encouraged to complete the TPACK surveys in the introduction video and an email that was sent through email to all registrants five and ten days after the course start date. At the beginning of the five-week *TMT* MOOC-Ed during February 2023, a pre-TPACK survey (see Appendix B) was included in the orientation module of the course following the course instructor welcome video. The TPACK survey was to assess participants' different knowledge domains for teaching mathematics with technology. During this time participants also completed the enrollment survey for demographic information.

During week three of the five-week course, a post-TPACK survey was made available in unit five and participants were emailed and encouraged to complete the survey after completing the MOOC-Ed units. At the end of the course, a post-TPACK survey (see Appendix B) was completed by participants. The pre-and post-survey was an identical measure and contained the same knowledge domain questions. According to enrollment data, MOOC-Ed participants report diverse professional experiences that include knowledge of technology and technology use in mathematics. To this end, measuring the TPACK of participants before and after the MOOC-Ed experience is important to measuring and analyzing participants' change in TPACK.

Data Collection Instrument. To measure participants' TPACK before the start of the *TMT* MOOC-Ed and after the course was completed, a TPACK survey (Appendix B) was administered. The Technological Pedagogical Content Knowledge (TPACK) survey developed by Zelkowski, Gleason, Cox, and Bismarck (2013) were adapted to this study. The survey consisted of twenty-two items categorized into four knowledge domains and was validated through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). Each survey item used a 5-point Likert scale response (SD = strongly disagree, D = disagree, N = neither agree nor disagree, A = agree, and SA = strongly agree) as a response anchor to report the participants' level of agreement with the statement (Vagias, 2006). The survey items measured four knowledge domains. The first six items (TK1-TK6) addressed the technological knowledge (TK) of the learner. The second domain consisted of five items (CK 9, 11, 12-14) that examined the content knowledge (CK) of the learner. The third set of five items measured pedagogical knowledge (PK17-21). The final domain consisting of six items evaluated technological pedagogical content knowledge (TPACK 51-53, 55, 59-60) (Zelkowski et al., 2013).

Data Analysis. Pre-and Post-TPACK surveys were analyzed using quantitative methodology. Likert scale items were exported into Excel and the data was analyzed using the Statistical Package for Social Science (SPSS) software. Quantitative analysis included descriptive statistics (means and standard deviations and mean differences) for each knowledge domain (TK, CK, PK) and for TPACK. A paired sample *t*-test was used to determine if there was a statistical difference between pre-and post-scores and the effect. A graphical representation will include the test statistic, degrees of freedom, p-value, and effect size for the aggregate sample of participants who completed the pre-and post-TPACK survey.

Data Collection and Analysis of Research Question 3

The qualitative and quantitative data collected for research questions one and two were analyzed in addition to enrollment survey questions pertaining to technology use and learning goals to examine RQ3-What is the nature of the relationship between highly active teacher learners' TPACK and their modes of discussion in the *Teaching Mathematics with Technology* MOOC-Ed?

Sample Participants and Data Collection. The sample to answer research question three included those MOOC-Ed participants who completed both the pre-and post-TPACK surveys and were determined to be highly active in the discussion forums. To address research question three the data collected from content analysis of the discussion forums (RQ1) was integrated with the statistical analysis of the surveys (RQ2) to understand the relationship between forum postings and their change in TPACK. Additionally, registered participants completed a demographics survey in the orientation unit. The survey contained four questions (Appendix F) that provided insight into participants' reasons for enrolling in the course, technology use, and their level of confidence using technology to teach mathematics. Also, the unit feedback surveys will be used for participant commentary to add an additional level of support on investigating any emerging trends or connections between highly active teacher learners modes and discussion and TPACK knowledge.

Data Analysis. In this study data integration occurred at the study design and method levels. The first level of integration occurred at the study design level where quantitative and qualitative data was collected in parallel. The data was analyzed independently after collecting each strand in attending to research questions one and two (Fetters, Curry, & Creswell, 2013). A second level of integration occurred at the methods level where the qualitative data sample was connected to the quantitative data sample through the sampling frame (Fetters, Curry, & Creswell, 2013). The third level of integration occurred to address research question three. This level of integration was the *point of interface*- an intersection in the study where two or more data sets are mixed (Guest, 2013). For this study, the intended purpose for "mixing" is to explain the relationship between teachers' TPACK knowledge and the types of discussions that occurred in the forums. Data consolidation referred to as "merging" will serve as a mixing strategy to integrate TPACK data and discussion forum content for analysis and comparison (Caracelli & Greene, 1993; Creswell & Plano Clark, 2007).

The analysis for research question three will center around two conjectures that address *quantity* and *quality*, respectively (Huang et al., 2014). The following definitions will support the analysis.

- *Quantity* refers to the average number of posts (original or replies) made by a highly active teacher learner in four units during the five-week professional learning MOOC-Ed.

- *Quality* refers to the frequency of dispositions categorized by the four productive online discussion model dispositions listed as (1) discuss to comprehend, (2) discuss to critique, (3) discuss to construct knowledge, or (4) discuss to share improved understanding.

The two conjectures that guide the analysis of research question three are listed below. The first conjecture *quantity* will explore the notion that participants who experience more TPACK growth were hyper engaged in the discussion forum relative to their highly active peers.
The second conjecture deals with the *quality* of discussion forum postings beyond discussions that seek to only comprehend course materials and resources.

Conjecture 1: Quantity–Participants who had the greatest gains in TPACK were more actively involved (i.e., initiated discussions and replied to other users more frequently) as compared to other highly active teacher learners.

Conjecture 2: Quality–Participants who had forum postings coded with disposition two (Discuss to Critique) and disposition three (Discuss to Construct Knowledge) and disposition four (Discuss to Share Improved Understanding) at a greater frequency compared to other highly active teacher learners experienced the greatest gains in their TPACK knowledge.

To investigate both conjectures qualitative data will be quantified after coding with counts and frequencies of disposition and learner actions contained in the Productive Online Discussion Model. The number of times codes appear will be in numerical form. Comparison will occur in matrix form using quantitative variables from TPACK findings and qualitative counts from the content analysis of discussion forums. In reference to conjecture one, the quality of discussion forum posts, the matrix will contain the aggregate of participants' TPACK knowledge domains with the frequency of dispositions and learner actions (see Teno, Stevens, Spernak, & Lynn, 1998, p. 442). Similarly, for conjecture two, matrix analysis will examine the highly active teacher learners productive online discussion model dispositions by frequency and the gains (if any) they experienced in each TPACK knowledge construct. Joint displays of data will be investigated for patterns and trends between discussion forum contribution and TPACK knowledge.

CHAPTER 4: RESULTS

Introduction

Chapter 4 presents the qualitative, quantitative, and integrated data findings to the three research questions in this study. This study examined the relationship between MOOC-Ed participants' involvement and participant interactions in discussion forums and their TPACK. Several demographic variables of interest included gender, geographical diversity, primary area of teaching specialization, type of organization, level of education, and years of teaching experience. In addition, participants reported their primary reasons for enrolling in the professional development course and current confidence level with using technology to teach mathematics. Pre- and post-surveys were administered to the *TMT* MOOC-Ed participants to collect quantitative data and discussion forum postings were evaluated using qualitative content analysis for teachers who completed the surveys.

Qualitative Analysis for Research Question 1

The qualitative data analysis for this section addressed the first research question for this study: *What is the nature of highly active teacher learners' modes of discussion within forum discussions in the Teaching Mathematics with Technology MOOC-Ed?* This section presents the results of the analysis conducted to identify highly active teacher learners' in the professional development course and the nature of their discussion forum contributions.

Active Participation

The purpose of research question one is to explore the nature of how educators are engaging in MOOC discussion forums. Of the total of 599 discussion forum threads in the course, 34 included a reply post from the course facilitators and there were no threads initiated by the facilitation team other than the forum question prompts. Facilitator replies were limited to unit one discussion forums and did not occur in the remaining units. There were a total of 565 remaining forum threads that were posted by MOOC-Ed registered participants across units one through four. Therefore, 94.32% of the interactions that occurred in the discussion forums were between course participants who posted to a discussion forum at least once without facilitator intervention. Of those remaining threads, 429 original or reply threads were posted from the 39 participants in this research study. Table 4.1 lists the categorized contributions of MOOC-Ed enrolled participants including facilitation team.

Table 4.1

Overall Contributions to the TMT Discussion Forums (N=599)

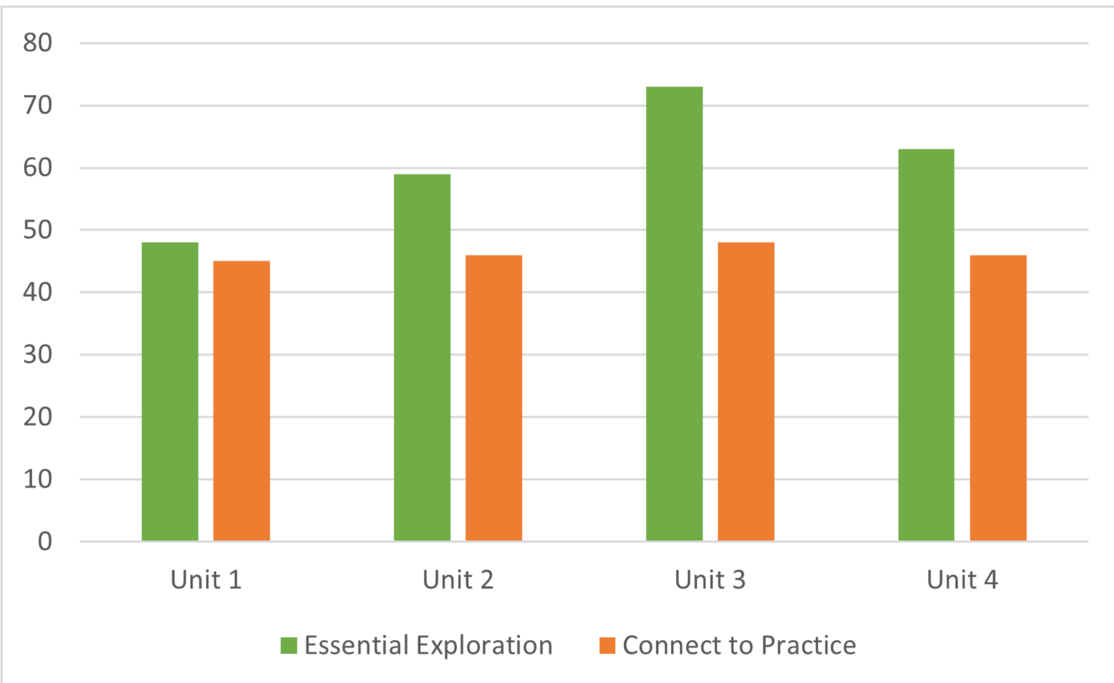
	Number of Posts	Percent of Total Posts
Facilitator & Observers (n = 4)	34	5.68%
Non-Research Participants (n = 111)	136	22.70%
Active Research Participants (n = 39)	429	71.62%

Each unit in the *TMT* professional development course had two sections termed Essential Exploration (EE) and Connect to Practice (CP) (see Appendix D) where discussion forum prompts were posted. Figure 4.1 displays the frequency of postings per section for units one through four. A total of 93 posts (21.7%) were made in unit one (48 EE and 45 CP) with 105 post contributions (24.5%) in unit two (59 EE and 46 CP). The greatest frequency of postings were 121 postings (28.2%) from unit three (73 EE and 48 CP). Finally, unit four consisted of 110 postings (25.6%) (63 EE and 47 CP). Forum contributors posted more frequently to the

Essential Exploration discussion forums (243 postings) than the Connect to Practice forums (186 postings). However, there was less variability within the frequency of postings in the CP forums (SD = 1.2) than with the EE forums (SD = 10.34).

Figure 4.1

Discussion Forum Post Frequency Per Unit



In this study, the aim of research question one was to examine participant interactions in the forums to explore patterns and occurrences of learner actions to establish potential relationships between dispositions in highly active participants. Active participants were those categorized as having posted an original thread or replied to another participant in at least one discussion forum in each unit. At this phase, criterion sampling was used as an informative strategy to exclude participants who were not consistent in posting to the discussion forums. To identify active participants, the total number of forum posts were cleaned by excluding posts from the facilitation team. Table 4.2 lists the frequency of postings for all 39 MOOC-Ed participants who posted to at least one forum.

Table 4.2

TMT MOOC-Ed Research Participant Posts by Unit (N=39)

ID Number	Unit 1	Unit 2	Unit 3	Unit 4	Total
1	7	4	4	4	19
2	3	2	2	2	9
3	2	4	4	5	15
4	2	2	2	2	8
5	2	4	6	3	15
6	2	3	3	3	11
7	2	1	2	3	8
8	2	2	3	2	9
9	2	1	4	4	11
10	2	3	2	2	9
11	2	2	2	2	8
12	2	4	4	4	14
13	2	2	4	3	11
14	2	3	3	2	10
15	2	4	2	2	10
16	3	2	3	2	10
17	2	2	2	1	7
18	2	2	3	2	9
19	2	2	3	2	9
20	2	3	4	4	13
21	3	4	4	4	15
22	2	2	2	2	8
23	2	2	2	2	8
24	2	2	2	3	9
25	2	3	2	2	9

Table 4.2 (continued)

26	2	2	2	2	8
27	2	4	3	2	11
28	2	2	2	2	8
29	7	7	7	8	29
30	2	2	2	2	8
31	2	2	2	2	8
32	4	4	3	3	14
33	2	1	2	2	7
34	2	2	2	2	8
35	2	3	5	4	14
36	2	2	2	2	8
37	2	2	4	2	10
38	2	3	4	3	12
39	2	4	7	7	20

Of the 39 active participants, the bottom 50% posted between seven and nine posts over four units. The top 50% of forum contributors posted between ten and twenty posts with the maximum number of posts being twenty-nine. Thirty-three of the 39 contributors posted consistently across all units with a standard deviation between 0.00 and 1.00. There were six participants who had more inconsistency in how often they posted to the forums (1, 3, 5, 9, 35, 39) having standard deviations ranging from 1.50 to 2.45.

Inclusionary Dispositions and Learner Actions

A frequency analysis was conducted on units one through four discussion forums (EE & CP) and discussion forum threads were coded for all 39 participants using the productive online discussion model as the a priori coding framework. The frequencies of each learner action (i.e., 2c-Challenging the ideas in others' posts) were yielded by counting the occurrences and learner actions in the forum postings. This was conducted through line-by-line analysis of each post.

Individual posts were coded as a single disposition and learner action (i.e., 1a) or coded as a combination of several single codes (i.e., 1a, 1b, 2a, 3b). Table 4.3 provides the number of total times a post was coded, and the frequency based on disposition and learner action by unit. Each table includes a per unit snapshot of dispositions and learner actions for each discussion forum.

There were a total of 558 single codes for the Essential Explorations and Connect to Practice discussion forums from units one through four. Overall, forum contributions with the greatest occurrence were coded as 1a referencing disposition one (discuss to comprehend) and learner action a (interpreting or elaborating the ideas by making connections to the learning materials) in all four units. The highest occurrence of code 1a occurred in Unit 1 CP (74.0%) and the lowest occurrence was in Unit 3 CP (40.3%). More than half of all discussion forum postings were coded as 1a with the average across all four units being 50.23%.

In unit one, disposition one comprised 77.2% while disposition one formed 8.30%. A single post was coded in disposition three (1.0%) and in disposition four (1.0%). While posts coded as ‘other’ made up 12.5% of all contributions. In unit two, disposition one was 63.6% of all codes and disposition two were 23.3%. Disposition three was listed at 7.1% and there were no posts categorized as disposition four. Forum contributions coded as ‘other’ were less frequent in this unit at 6.5%. Unit three comprised disposition one (56.0%), however, this unit also had the highest frequency of disposition two postings (28.4%). Disposition three made up just 0.05% of posts while there were no posts from disposition four. Forum contributions coded as ‘other’ (15.1%) were higher than those of units one and two. Unit four had the lowest frequency of disposition one (48.0%) while disposition two was 27.5%. Disposition three had the highest frequency in unit four (5.7%) and two posts were coded in disposition 4 (1.3%). Forum contributions coded as ‘other’ had the highest frequency across all units at 17.6%.

Table 4.3

a Priori Codes Counts and Frequencies (N=39)

Unit 1 Dispositions and Learner Actions	Unit 1 EE (58)		Unit 1 CP (50)	
	Count	Percent (%)	Count	Percent (%)
1. Discuss to Comprehend				
a) Interpreting or elaborating the ideas by making connections to the learning materials	33	56.9	37	74.0
b) Interpreting or elaborating the ideas by making connection to personal experiences	5	8.6	4	8.0
c) Interpreting or elaborating the ideas by making connections to other ideas, sources, or references	4	6.9	0	***
2. Discuss to Critique				
a) Building or adding new insights or ideas to others' posts	4	6.9	4	8.0
b) Challenging the ideas in the text/MOOC content	1	1.7	***	***
c) Challenging the ideas in others' posts	***	***	***	***
3. Discuss to Construct Knowledge				
a) Comparing and contrasting views from the text or others' posts	***	***	1	2.0
b) Facilitating thinking and discussions by raising questions	***	***	***	***
c) Refining and revising one's own view based on the texts or others' posts	***	***	***	***
4. Discuss to Share Improved Understanding				
a) Summarizing the personal learning experiences of online discussions	***	***	***	***
b) Synthesizing discussion content	1	1.7	***	***
c) Generating new topics based on a review of previous discussions	***	***	***	***
5. Other	10	17.0	4	8.0

Table 4.3 (continued)

Unit 2 Dispositions and Learner Actions	Unit 2 EE (103)		Unit 2 CP (62)	
	Count	Percent (%)	Count	Percent (%)
1. Discuss to Comprehend				
a) Interpreting or elaborating the ideas by making connections to the learning materials	41	40.2	36	58.1
b) Interpreting or elaborating the ideas by making connection to personal experiences	7	6.9	9	14.5
c) Interpreting or elaborating the ideas by making connections to other ideas, sources, or references	6	5.9	1	1.6
2. Discuss to Critique				
a) Building or adding new insights or ideas to others' posts	15	14.7	6	9.7
b) Challenging the ideas in the text/MOOC content	21	20.6	1	1.6
c) Challenging the ideas in others' posts	***	***	***	***
3. Discuss to Construct Knowledge				
a) Comparing and contrasting views from the text or others' posts	3	2.9	1	1.6
b) Facilitating thinking and discussions by raising questions	5	4.9	3	4.8
c) Refining and revising one's own view based on the texts or others' posts	***	***	***	***
4. Discuss to Share Improved Understanding				
a) Summarizing the personal learning experiences of online discussions	***	***	***	***
b) Synthesizing discussion content	***	***	***	***
c) Generating new topics based on a review of previous discussions	***	***	***	***
5. Other	5	4.9	5	8.1

Table 4.3 (continued)

Unit 3 Dispositions and Learner Actions	Unit 3 EE (90)		Unit 3 CP (62)	
	Count	Percent (%)	Count	Percent (%)
1. Discuss to Comprehend				
a) Interpreting or elaborating the ideas by making connections to the learning materials	43	47.8	25	40.3
b) Interpreting or elaborating the ideas by making connection to personal experiences	7	7.8	9	14.5
c) Interpreting or elaborating the ideas by making connections to other ideas, sources, or references	***	***	1	1.6
2. Discuss to Critique				
a) Building or adding new insights or ideas to others' posts	13	14.4	9	14.5
b) Challenging the ideas in the text/MOOC content	11	12.2	9	14.5
c) Challenging the ideas in others' posts	1	1.1	***	***
3. Discuss to Construct Knowledge				
a) Comparing and contrasting views from the text or others' posts	***	***	***	***
b) Facilitating thinking and discussions by raising questions	1	1.1	***	***
c) Refining and revising one's own view based on the texts or others' posts	***	***	***	***
4. Discuss to Share Improved Understanding				
a) Summarizing the personal learning experiences of online discussions	***	***	***	***
b) Synthesizing discussion content	***	***	***	***
c) Generating new topics based on a review of previous discussions	***	***	***	***
5. Other	14	15.6	9	14.5

Table 4.3 (continued)

Unit 4 Dispositions and Learner Actions	Unit 4 EE (77)		Unit 4 CP (56)	
	Count	Percent (%)	Count	Percent (%)
1. Discuss to Comprehend				
a) Interpreting or elaborating the ideas by making connections to the learning materials	32	41.6	24	42.9
b) Interpreting or elaborating the ideas by making connection to personal experiences	3	3.9	1	1.8
c) Interpreting or elaborating the ideas by making connections to other ideas, sources, or references	3	3.9	1	1.8
2. Discuss to Critique				
a) Building or adding new insights or ideas to others' posts	11	14.3	11	19.6
b) Challenging the ideas in the text/MOOC content	8	10.4	6	10.7
c) Challenging the ideas in others' posts	***	***	***	***
3. Discuss to Construct Knowledge				
a) Comparing and contrasting views from the text or others' posts	***	***	1	1.8
b) Facilitating thinking and discussions by raising questions	3	3.9	1	1.8
c) Refining and revising one's own view based on the texts or others' posts	3	3.9	***	***
4. Discuss to Share Improved Understanding				
a) Summarizing the personal learning experiences of online discussions	***	***	***	***
b) Synthesizing discussion content	2	2.6	***	***
c) Generating new topics based on a review of previous discussions	***	***	***	***
5. Other	12	15.6	11	19.6

Figure 4.2

Dispositions Per Unit (N=39)

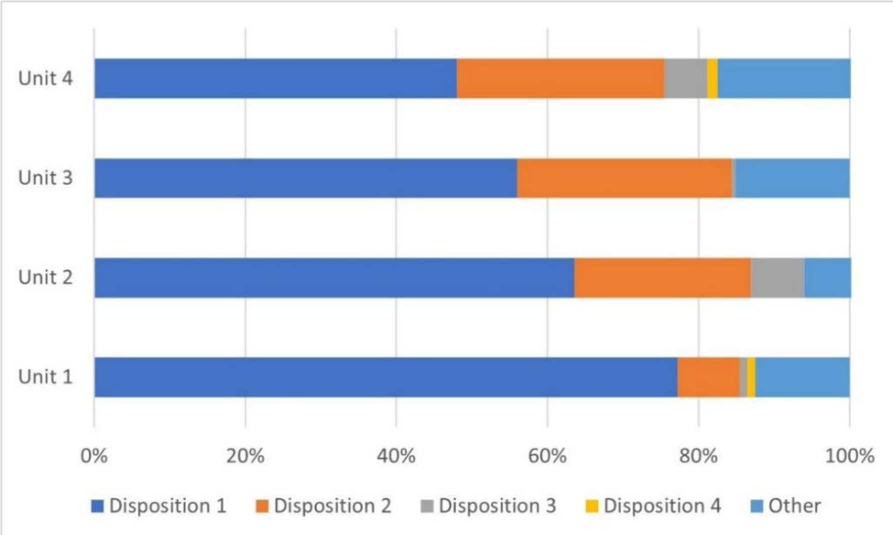


Figure 4.2 provides the percentage of dispositions coded per unit. As the MOOC-Ed course progressed, the percentage of dispositions two through four were more likely to occur.

Figure 4.3

Trends in the Percent of Dispositions Per Unit (N=39)

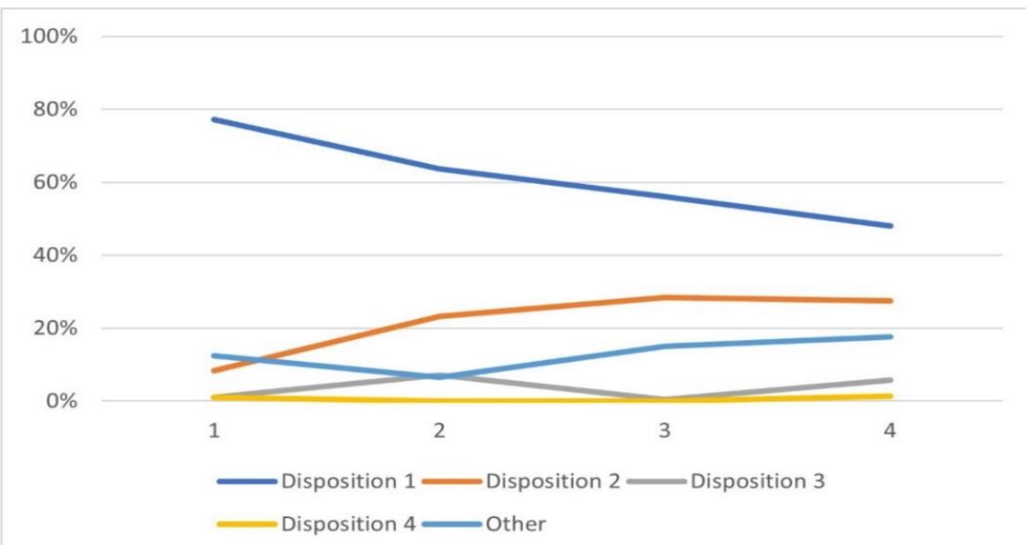


Figure 4.3 depicts the percentage of forum contributions coded per distribution by unit. The line graph shows a decrease in the number of postings where participants discuss to comprehend and a trending up of discussions that critique, construct knowledge and share understanding. As participants progressed through the MOOC-Ed forums there were higher percentages of discussions coded as dispositions two through four and contributions coded as disposition one occurred less frequently.

Highly Active Participants

Highly active participants were considered the top 25% of forum posters from the thirty-nine participants who contributed at least a single post to each unit of the course. Table 4.4 lists the top 10 contributors (13 or more posts) to the *TMT* MOOC-Ed forum discussions. Combined they posted a total of 168 discussions comprising 39.16% of research participant postings.

Table 4.4

Highly Active Participant Forum Contributions

Participant	Number of Posts	% of Total Posts (n=429)
Cory	19	4.43%
Mike	15	3.59%
Jamie	15	3.59%
Sal	14	3.26%
Sarah	13	3.00%
Jane	15	3.59%
Mark	29	6.76%
Simon	14	3.26%
Jessica	14	3.26%
Karen	20	4.66%
Total	168	39.16%

Table 4.5 provides a synopsis of highly active posters demographic profiles. The table shows that nine were from the United States (US) and one was from Thailand. Six of the ten were female. Highly active participants years of educational experience was wide-ranging between two and forty years. However, 90% of participants had from nine to forty years of experience with six of ten having 20 or more years. Combined, these participants had an average of 19.9 years of teaching experience. All but one participant worked in the K-12 setting. The 39 participants in this study presented a diversity of educational levels, 52% indicated having a doctoral or master's degree with 46% holding a 4-year degree. The educational level of the highly active participants were slightly higher with 70% holding an advanced degree (master's or PhD).

Table 4.5

Highly Active Participants Demographics

Participant	Gender	Role	Level of Education	Years of Experience	Country
Cory	Female	6-8 Teacher	4-Year	2	US
Mike	Male	9-12 Teacher	Masters	14	US
Jamie	Female	9-12 Teacher	Masters	20	US
Sal	Male	6-8 Teacher	Masters	9	Thailand
Sarah	Female	9-12 (Other)	4-Year	21	US
Jane	Female	K-6 Mentor	Masters	28	US
Mark	Male	6-8 Curriculum Coach	4-Year	29	US
Simon	Male	College Professor	Doctoral	40	US
Jessica	Female	6-8 Teacher	Masters	27	US
Karen	Female	9-12 Teacher	Masters	9	US

Table 4.6

a Priori Codes Counts and Frequencies (N=10)

Units 1-4 Dispositions and Learner Actions	EE (139 codes)		CP (85 codes)	
'Highly Active' Forum Contributions	Count	Percent (%)	Count	Percent (%)
1. Discuss to Comprehend				
a) Interpreting or elaborating the ideas by making connections to the learning materials	65	29.0	48	21.4
b) Interpreting or elaborating the ideas by making connection to personal experiences	8	3.6	7	3.1
c) Interpreting or elaborating the ideas by making connections to other ideas, sources, or references	9	4.0	2	0.9
2. Discuss to Critique				
a) Building or adding new insights or ideas to others' posts	13	5.8	9	4.0
b) Challenging the ideas in the text/MOOC content	18	8.0	8	3.6
c) Challenging the ideas in others' posts	1	0.4	0	***
3. Discuss to Construct Knowledge				
a) Comparing and contrasting views from the text or others' posts	1	0.4	1	0.4
b) Facilitating thinking and discussions by raising questions	6	2.7	2	0.9
c) Refining and revising one's own view based on the texts or others' posts	1	0.4	0	***
4. Discuss to Share Improved Understanding				
a) Summarizing the personal learning experiences of online discussions	0	***	0	***
b) Synthesizing discussion content	1	0.4	0	***
c) Generating new topics based on a review of previous discussions	0	***	0	***
5. Other	16	7.1	8	3.6

Table 4.6 lists the forum contributions for those ten participants in this study categorized as highly active participants. Of the 558 single codes for the Essential Explorations and Connect to Practice discussion forums from units one through four listed per unit in table 4.3, 224 codes (40.14%) were generated from the highly active participants The frequencies of code occurrences were totaled for 168 forum discussion postings and summarized in this table. Discussion forum contributions were similar to those of all 39 participants in that disposition one had the greatest occurrence (62.0%). Disposition two was identified in 21.8% of codes while disposition three was 4.9% of all codes specified. A single post was coded in disposition 4 (0.40%) and 10.7% of posts were considered 'other'.

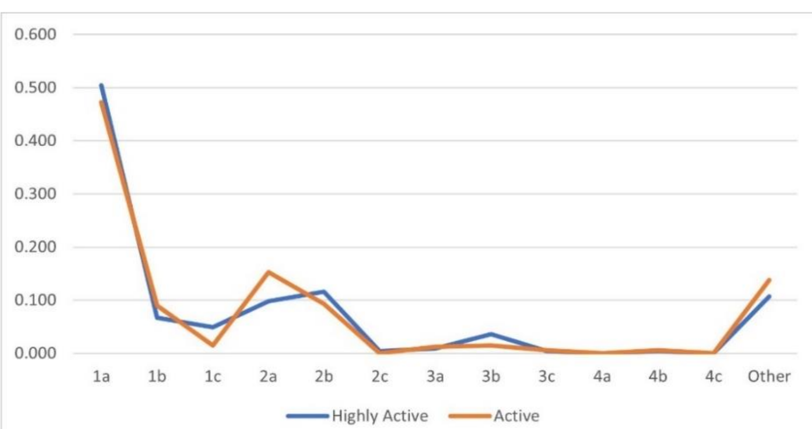
When comparing highly active participants to active participants, the frequency of postings with regard to dispositions are similar. Active participants discussed to comprehend 57.8% of the time and discussed to critique at a slightly higher rate than highly active participants at 24.6%. Both highly active and active participants had eleven occurrences of discussing to construct knowledge. Active participants posted 3.3% on disposition three. However, highly active participants posted at a slightly higher rate. Discussion forum postings that references discussion to share improved understanding were rare for both groups of participants at 0.40% for highly active participants and 0.60% for active participants. Given the 429 forum contributions that were coded, one post was coded with learner action 2c-challenging the ideas in others' posts and no posts were coded with learner actions 4a-*summarizing the personal learning experiences of online discussions* or 4c-*generating new topics based on a review of previous discussions*. Figure 4.4 provides a graphical representation of the relationship between each learner actions across all four units of both highly active and active participants.

Table 4.7

Frequency of Learner Actions for Highly Active and Active Participants

Learner Action	Highly Active (n=10)		Active (n=29)	
	Count	Percent (%)	Count	Percent (%)
Discuss to Comprehend				
1a	113	50.4	158	47.3
1b	15	6.7	30	9.0
1c	11	4.9	5	1.5
Total	139	62.0	193	57.8
Discuss to Critique				
2a	22	9.8	51	15.3
2b	26	11.6	31	9.3
2c	1	0.4	0	0.0
Total	49	21.8	82	24.6
Discuss to Construct Knowledge				
3a	2	0.9	4	1.2
3b	8	3.6	5	1.5
3c	1	0.4	2	0.6
Total	11	4.9	11	3.3
Discuss to Share Improved Understanding				
4a	0	0.0	0	0.0
4b	1	0.4	2	0.6
4c	0	0.0	0	0.0
Total	1	0.4	2	0.6
Other	24	10.7	46	13.8

Figure 4.4



Highly Active Participants Modes of Discussion

Next, the discussion forum postings for highly active participants were explored further by examining patterns and relationships between dispositions and learner actions to provide more insight into their modes of discussion and how they interacted with other learners. Table 4.8 describes the most common combinations of learner actions and how often they occurred in units one through four. Within and across forums, the greatest percentage of discussions were coded as 1a only followed by discussions coded as 2a only. The greatest percentage of discussion forums coded with two or more codes were (1a, 1b) and (1a, 2b) at 3.6%.

Table 4.8

Combinations of Learner Actions (N=169)

Dispositions	Learner Actions	Count	Percent (%)
1	1a	79	46.7
	1b	3	1.8
	1c	3	1.8
	1a, 1b	6	3.6
	1a, 1c	3	1.8
2	2a	11	6.5
	2b	7	4.1
1, 2	1a, 2a	3	1.8
	1a, 2b	6	3.6
	1a, 1b, 2b	3	1.8
	1a, 2a, 2b	3	1.8
2, 3	2b, 3b	2	1.2
1, 2, 3	1a, 2b, 3b	2	1.2
Combinations of Dispositions (not listed)		14	8.3
Other		24	14.2
	Total	169	

Table 4.9 shows the code counts per unit for highly active participants. Unit two has the highest frequency with 68 codes followed by unit three with 58 codes. Unit four followed with 60 codes and unit one has the least number of codes with only 38.

Table 4.9

Highly Active Participants Code Counts Per Unit

	Count	Percent (%)
Unit 1	38	16.7
Unit 2	68	30.4
Unit 3	58	25.9
Unit 4	60	26.8

As mentioned earlier, the greatest percentage of posts were coded either 1a or had a combination of codes that included a 1a coding. Figure 4.5 depicts the trends in distributions for each unit in the MOOC-Ed. Disposition one was coded in unit one 76.32% of the time while dispositions two through four was coded 10.53%. In unit two, there was a decrease in disposition one coding (61.76%) and an increase in forum postings coded as dispositions two through four (32.35%). This trend held across units three and four. Disposition one made up 62.07% of unit three and 53.33% of unit four while dispositions two through four were 25.86% and 33.33 % respectively.

Figure 4.5

Trends in Dispositions Per Unit

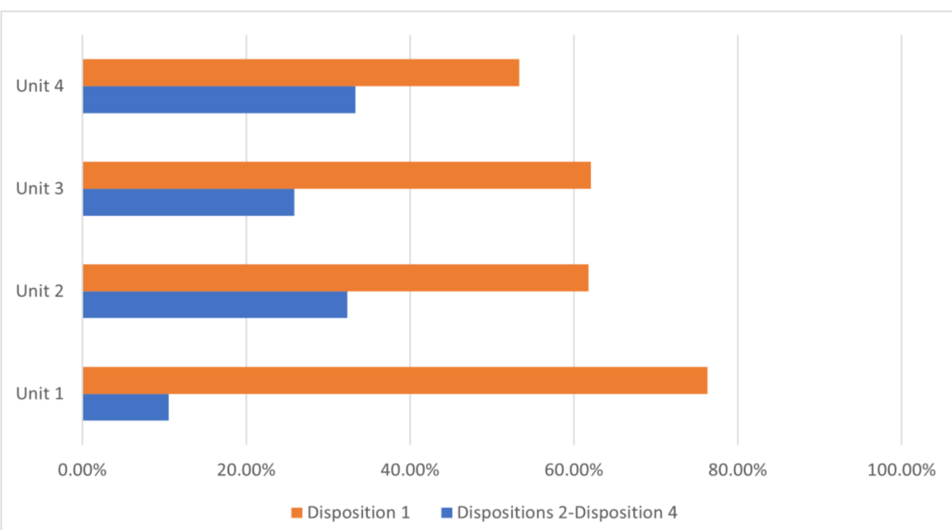
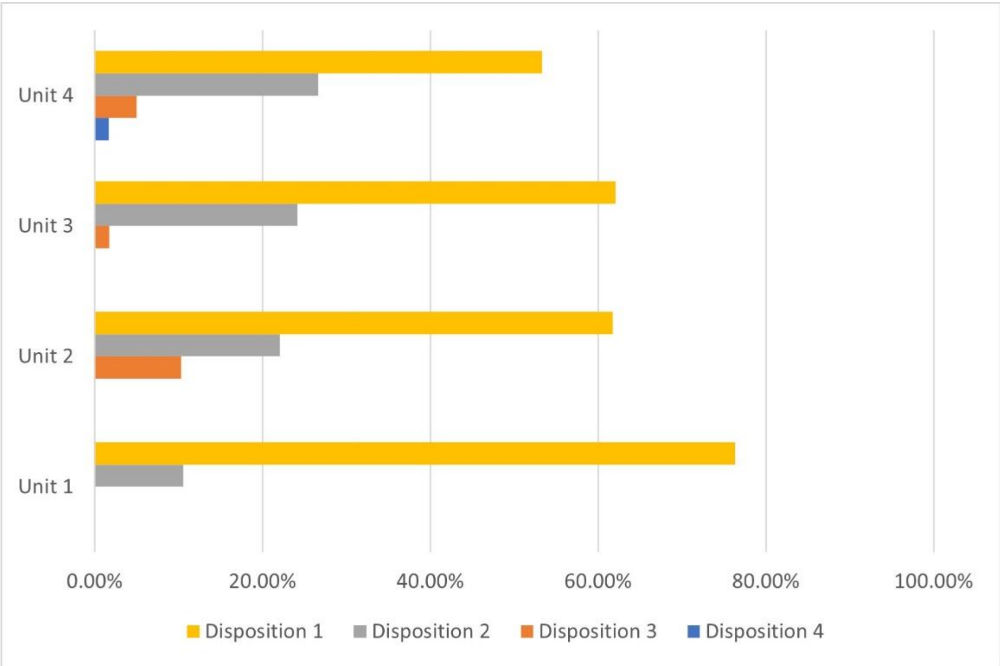


Figure 4.6 provides a parsed view of how dispositions were distributed per unit across the professional learning course. A detailed examination of the modes of discussion in the forums among highly active participants exhibit greater involvement in dispositions two through four as the course progresses. In unit one discussions were confined to dispositions one and two. However, unit two had 10.9% of the codes categorized in disposition three. Unit three had 24.14% of codes in disposition two and 1.72% of codes in disposition three. Unit four had the most diversity with 25.67% coded in disposition two, 5.0% coded in disposition three, and 1.67% in disposition four.

Figure 4.6

Frequency of Dispositions Per Unit



Unit One Modes of Discussion

Unit one Essential Exploration (EE) and Connect to Practice (CP) discussion forums analyzed student thinking and students' work. The EE forum focused on students' use of technology while the CP forum compared students' work with and without technology to participants own work (see Appendix C). For reference, the forum questions are provided in Appendix D of this study. Unit one had the highest frequency of disposition one where participants discussed to comprehend. Most forum postings were coded with 1a only or 1a was included in the combination of codes. In unit one, 29 of 33 (87.9%) postings received coding 1a. An example of a discussion forum post that was coded as 1a only is below. The commentary provided by *Mike*, a high school mathematics teacher, speaks to the specific operations performed by students in the penny circle task in the EE discussion forum.

> The students were able to change the graphs to compare which type of equation most closely aligned to their information. They were definitely about to rule out one that was wrong but could go between the other two adjusting as they went. Desmos was able to come up with an equation based on the type of graph they thought it was and where they placed it around their points. Doing the activity: I loved being able to look at the different sized circle to come up with some points, without needing to have a thousand pennies for students on that day. It was not a big setup. It was cool being able to move and manipulate the equations to see which one matched and being able to change and try something else to compare without starting from scratch. (Unit 1-EE, 1a)

Additionally, unit one had two postings that had combinations of dispositions one and two. More specifically, *Mark* contributed to the forum stating,

> I agree also! You have to spark the curiosity. This Desmos lesson is similar to the 3 Act Task of Make Math Moments that Matter. Spark the curiosity by withholding information and asking what to make an estimate. Supply some information and allow for problem solving. The last part would be the reveal and consolidation. Once students' interest is piqued, then they want to learn math to see how close their estimate is (Unit 1-EE, 1a, 1c, 2a)

Mark engages the forum through initiating agreement with statements made by another participant and adds his own insight to the previous post. Simultaneously, he references a math task that is not included in the MOOC-Ed course material for this unit to support his discussion on sparking students' interest in mathematical learning. *Simon,* a college professor with 40 years of teaching experience contributes to the forum similarly. However, he offers suggestions that challenges the MOOC content. He affirms the following:

> The task included multiple representations, predictions, model development, and generating data by experimentation via Desmos and I would add doing real hands-on experimentation with pennies and use circular container lids. Pooling data in Google Sheets would allow for a quick examination of the class results plus see variation. This would lead to considering variation. An element missing in this activity is the error and its behavior. The pennies can never fill the complete area plus did students pack them in an efficient way. Error behavior could be investigated. (Unit 1-EE, 1a, 1c, 2b)

In a similar post in the same discussion *Simon* follows up with another post giving reference to resources outside the MOOC-Ed stating, "here is a Google Sheets spreadsheet that takes an error analysis approach to the Penny Circle Task https://docs.google.com/spreadsheets/d/1UVb6n2." (Unit 1-EE, 1c)

Mark contributed to the unit one connect to practice forum differently than all other contributors. He builds on and adds his own insight while replying to two other participant posts. Although he references functions and technology, he excludes mentioning specific technologies utilized in unit one course materials nor the types of functions discussed in the videos. In the first post he affirms, "so, whether to use technology or not depends on where the students learning is. If they understand the types of functions, they most definitely, they should use the technology to determine the best regression for a particular data set." (Unit 1-CP, 2a) He continues the conversation by following up with another comment.

> That depends on what the students have already learned. If they understand the type of functions, then not using the technology distracts from their learning. If they do not understand the types of functions, then using technology actually retards their learning. (Unit 1-CP, 2a).

In unit one, forum prompts were designed to analyze student thinking and student work. The greater percentage of postings discussed to comprehend in regard to the learning tasks and videos within the MOOC. The remaining posts referenced individual experiences and external resources or sought to add to other posts. In the next section, unit two modes of discussion will be examined.

Unit Two Modes of Discussion

Unit two Essential Exploration (EE) and Connect to Practice (CP) discussions consisted of four forums. The EE had two forums where participants shared ideas and resources and analyzed an algebra task focused on how technology was used. Both CP forums analyzed tasks with geometry content and statistics content (see Appendix C). Similar to unit one, disposition one had the highest frequency of codes. However, posts coded as disposition two (discuss to critique) and disposition three (discuss to construct knowledge) occurred at a much higher frequency than in unit one. There were a total of 41 posts in unit two. Of those 41 posts, 16 posts (39.0%) included at least a single code from dispositions two or dispositions three or a combination of both dispositions. Whereas unit one had 10.32% of posts categorized as dispositions two or three, unit two had a considerable amount more involvement with those dispositions. Forum contributions in unit two discussed to critique (D2) and discuss to construct knowledge (D3) 32.35% of the time. As participants were more involved in dispositions two and three in unit two, across all discussion forums a number of posts challenged the ideas of the MOOC content (10 occurrences) while others raised questions to facilitate thinking and discussion (5 occurrences). These posts were either codes with 2b (Challenging the ideas in the text/MOOC content) or 3b (Facilitating thinking and discussion by raising questions).

Sarah, a high school educator with 21 years of experience refers to the materials accessed in the unit based on her lack of experience with using GeoGebra. In this post, she shares her thoughts and ideas with her colleagues. Sarah refers to the frustration between the materials and her own learning experience and critiques the task given her difficulties.

> I think the technology tool is great if you know how to use it. Having never used the program before it was quite cumbersome and frustrating to try to figure out how to use it on 3 sets of data. I assume that this would not be the first assignment given with this technology and that smaller shorter lessons would be done previously so that the technology would be the amplifier that it was designed to be and not a hinderance to the assignment. (Unit 2-EE, 1a, 1b, 2b)

In units two, three, and four *Sal* contributed to each forum under learner actions 1a & 2b. In his unit two post on how the technology was used as an amplifier and reorganizer, he makes a connection to the learning resources while commenting on potential improvements to using the tool.

> The technology in this case seemed to be used as an amplifier but surely needed some improvement as it might have been difficult for the students to plot the data in the tables. I assume it would have been quicker if done by hand. (Unit 2-EE. 1a, 2b)

Similar to Sarah, *Jane* shares her thoughts and ideas openly with her colleagues. Rather than simply discussing to comprehend, Jane demonstrates her willingness to compare and contrast her learning experiences of using GeoGebra with the affordances of the tool itself. She understands the value of GeoGebra in supporting student learning and simultaneously expresses her frustration with the technology tool.

> I absolutely love the types of tasks that I see on GeoGebra but have to admit that using the app usually makes me want to throw something across the room. I find the tools very difficult to navigate and it kept deleting my work from the table when I went back to collect more data about animals for each second of the race. There are definitely benefits to this type of task, showing different rates of speed, changes in speed, using this visual format that is easily editable and would lead to great discussions (Unit 2-EE, 1a, 1b, 3a)

Moreover, *Karen* also recognizes the value of the task when she agrees with another participant. Like Jane, she critiques the task and poses a question that has the potential to promote more discussion. She advances the discussion stating,

> I agree. I like the idea of this assignment, but I still feel like I would have to write the data down on paper and then put into the spreadsheet. I feel like there would have to be a

lot of front loading on the technology usage prior to the activity so would you have time to complete the activity? (Unit 2-EE, 2b, 3b)

Like unit one forum postings, unit two discussion had a high percentage of discussion that centered around comprehension of the MOOC materials, videos, and activities. However, participants started replying more to their colleagues postings. In unit two, participant contributions referenced materials and other tools outside of the MOOC content when posting more frequently. Additionally, more discussion critiqued the MOOC content and participants asked questions to their colleagues to encourage reflection and move discussions forward.

Unit Three Modes of Discussion

Unit three Essential Exploration (EE) and Connect to Practice (CP) discussions consisted of six forums. The EE had three forums. In the first forum colleagues analyzed students' use of technology in a geometry task. The second forum they reflected on their own exploration of a geometry task, and in the third forum colleagues shared ideas and resources. All three CP forums had colleagues reflecting on how they explored one of three tasks involving functions, geometry or statistics while analyzing the task and student thinking (see Appendix C).

Like units one and two, most of the discussions centered on discussing to comprehend by making connections to the MOOC-Ed learning materials. There were 49 posts in unit three. Of those 49 posts, 15 posts (31.0%) included at least a single code from dispositions two or dispositions three. Forum contributions in unit three discussed to critique and discuss to construct knowledge 25.86% of the time. Similar to unit two, there is a greater frequency of forum contributions involving discussion that makes connections to personal experiences, discussion that critiques

MOOC content (i.e., student thinking, tasks), and discussion to construct knowledge from asking questions.

In reference to making connections to personal experiences, *Karen* reflects on her own learning with the mystery learning task and relates her experiences with those of her current students and the difficulties they may encounter working with the task. She noted, “I like the idea but the population of students that I teach would get frustrated and overwhelmed by this task and shut down. I feel like there are too many points to look at all at once” (Unit 3-EE, 1b). In another post, *Karen* mentions the triangle inequality task and her previous experiences with completing this task in class with hands on manipulatives stating, “I have done this activity with toothpicks before and it worked well” (Unit 3-CP, 1b). *Jamie* also responds to the forum by making a connection between the statistics task and her personal experiences. She expressed:

> I really enjoyed this task, but that might be because my daughter is a high school junior and we're currently looking at colleges. I think that by encouraging students to develop their own questions using this activity and encouraging them to dive deeper this could be a cognitively demanding task. (Unit 3-CP, 1a, 1b)

In unit three CP, *Jane* references the task in her discussion post and speaks to having experience with this standard in her class and the difficulties she encountered with the MOOC content.

> The task did require direct manipulation and was an essential component of the task as they changed the lengths of the sides in order to check if it would form a triangle. According to the handout, this was a middle school classroom. Based on that info, I would classify this as a low-level cognitive demand task because this standard is introduced in 4th grade. I've done similar tasks with 4th grade classes using other interactive sites and there are also tasks that have students use angles or Geoconnectors

> which provides hands on manipulation of the sides and figures. I did use the task analysis guide after viewing the video and trying out the task and found that this task lacked the opportunity for students to explore. They were asked to make a conjecture using very little information. (Unit 3-CP,1a, 1b, 2b)

In his contribution, Simon takes advantage of the forum prompt to critique the task and is blunt in questioning the way the activity was used and offers what he thinks to be a more straightforward approach to introducing students to the technology tool. He also poses a question stating that "this had to be one of the worst ways to introduce transformations!!! Examining an object, such as a triangle or a plotted function seems to me to be easier. Do students find this to be frustrating? Are they lost"? **(**Unit 3-EE, 2b, 3b)

In unit three, course participants had the opportunity to reflect on their own exploration of technological tasks and critique student thinking while analyzing student work. The structure and nature of the discussion forum prompts contributed to the frequency of forums that discussed to critique and construct knowledge, in particular, those that challenged the ideas in the course content.

Unit Four Modes of Discussion

Unit four Essential Exploration (EE) and Connect to Practice (CP) discussions included five forums. The EE had three forums. Participants analyzed students' discussions on a statistics task and shared their analysis in the forum with their colleagues. In the second forum, participants reflected on their own exploration of statistical tasks, and in the third forum participants shared ideas and resources with their colleagues (see Appendix C). Again, most forum contributions focused on discussing to comprehend by making connections to the course resources and learning materials. There were 46 posts in unit four with 16 posts (34.8%) included codes from dispositions two or dispositions three with one discussion in disposition four where the participant discussed to share improved understanding. Forum contributions in unit four discussed to critique, construct knowledge, and improve understanding in 33.33% of their posts. Worth noting, unit four had the least frequent posting that discussed to comprehend. Most forum contributions were comprised of making connections between their experiences with the learning materials and personal experiences, referring to resources outside the course to support peer learning opportunities, and building or adding their own observations to their colleagues' postings. Furthermore, participants also raised questions, critiqued teacher-led discussions, revised their own thinking, and synthesized discussion content.

Jessica's post refers to the avatar used in the course and relates that experience with her personal experiences with students she has taught in class.

> I am not an upper math teacher, so I was a little confused at first, but I caught on (it's been a while since I have done that) I liked the questions, but I would rather a teacher facilitate that, rather than an animated voice. MY students tune out those animated sounded voices. They would be more successful if their teacher would guide them through it. It kind of seemed rushed, but I do like the problem and with some discussion, it could be a great activity. (Unit 4-CP, 1a, 1b)

Jamie provides a critique of the technology tool and gives a brief analysis of the teacher orchestrated discussion saying,

> I found the Web Sketch pad much easier. I would have to learn GeoGebra better before I tried this task in that program with students. I think the teacher could use some "What if

> I do this..." Types of questions to see where the students are thinking? (Unit 4-CP, 1c, 2b)

Instead of discussing GeoGebra, Sal contributes his analysis on using CODAP, a dynamic statistical software tool for the first time. He shares,

> I think the graph was overly complicated and did not give enough information about the graph. It seemed like too cognitively overloading and by the 2 graphs given. Also having never used CODAP, kind of held me back a bit However if done properly, I think that this can easily go on a debate section and a group project/presentation! (Unit 4-EE, 1a, 2b)

While sharing ideas and resources with colleagues in another discussion forum, *Simon* offers an alternative technological tool as a graphing option and posing a question to advance discussion noting, "the Gapminder tool produces a phenomenal busy graph www.gapminder.org/tools-How do you lead up to using this type of graph? (Unit 4-EE, 1c, 3b). Similar to Sal and Simon, this was many participants first experience with using CODAP to graph large data sets. In the third forum in the essential exploration discussion, Simon initiates a conversation and states,

> Cognitive overload? Is this way too much information displayed at once for novice learners such as students? I think you need to examine many simpler plots before jumping into the CODAP data sets. I'm not sure we introduce enough multivariable data and its behavior in math and science classes. (Unit 4-EE, 1a, 2b, 3b)

Several participants followed up in agreement with Simon's sentiment when asked how the multiple representations of CODAP afforded or constrained their exploration of the data. Synthesizing all the discussion content in this conversation, *Mark* speaks to the affordances of the tool in moving students learning to higher levels of critical thinking when he tells the group,

> I'm sorry to hear that. There is time needed to be able to use all the features of the application, but I do think it is user-friendly. I really like the application and its use in the classroom to move our students from calculators to problems solvers. (Unit 4-EE, 2a, 4b)

In unit four, course participants analyzed discussions, reflected on their own exploration, and shared ideas and resources with their colleagues. Similar to unit three, the design and focus of the discussion forum prompts provided the framework for postings that discussed to critique and construct knowledge by building on others' posts and offering suggestions for improvement on the activities and tasks within the unit.

Quantitative Analysis for Research Question 2

The second research question addressed for this study was the following: *What effect does participation in the Teaching Mathematics with Technology MOOC-Ed have on highly active teacher learners' TPACK?* Quantitative data analysis to investigate research question two included descriptive and inferential statistical methods. This section begins with an analysis of level of normality for parametric testing followed by a descriptive analysis of TPACK survey responses. Subsequently, data analysis on survey results were conducted on active participants and highly active participants using paired sample testing on comprehensive TPACK scores and separate TPACK knowledge domain scores.

TPACK Survey Assessment

The TPACK survey scores were collected from thirty-nine registered participants who completed both the pre-and post- surveys during the spring of 2023. Since the sample was of size 39 ($n > 30$) in this research study, all quantitative testing followed the assumption that data was normally distributed (Abu-Bader, 2021; Ghasemi & Zahediasl, 2012). However, some normality testing was conducted to evaluate the conditions of normality (i.e., skewness and kurtosis) within and across knowledge domains. Descriptive statistical analysis was calculated using the SPSS software program for each question of the survey. Summary statistics in Table 4.2 were organized by domain and included the measures for mean, standard, deviation, skewness, and kurtosis. A combination of descriptive and theory-driven graphical and numerical methods listed in Table 4.1 were employed to conduct analysis of the normality of each distribution (Park, 2015).

Table 4.10

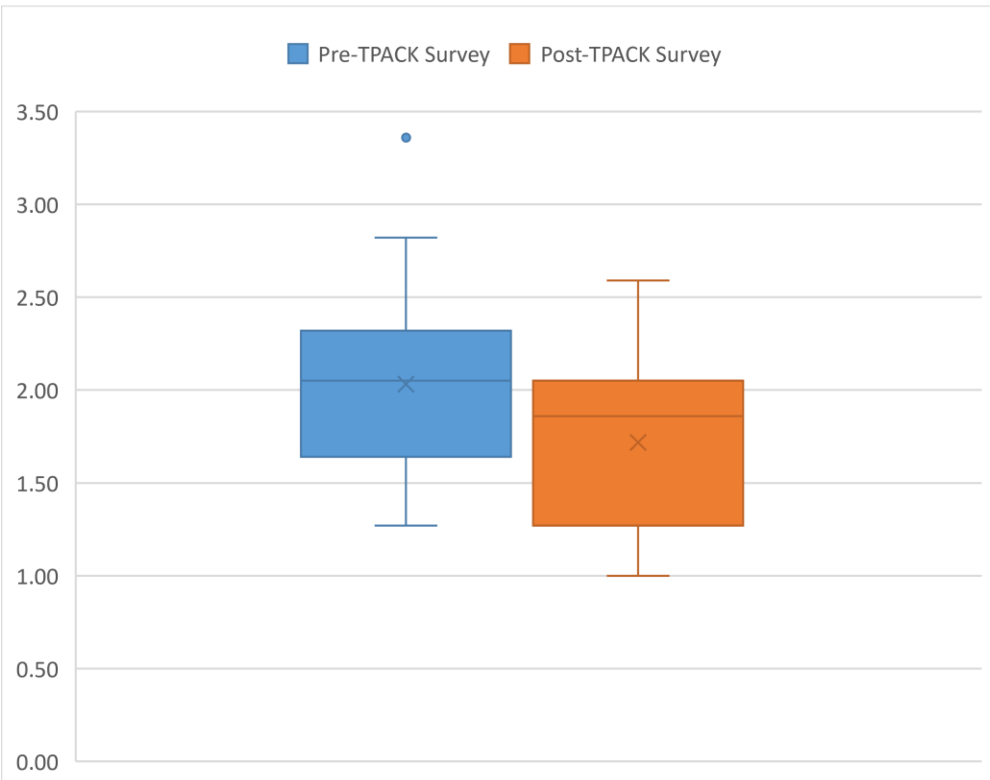
Summary of Methods for Normality Testing

	Graphical	Numerical
Descriptive	Box plot	Skewness Kurtosis
Theory-driven	Q-Q plot	Shapiro-Wilk

From the graphical perspective, box plots and normal quantile-quantile (Q-Q) plots were analyzed for each survey. In a boxplot, when data are normally distributed, the first and third quartiles are symmetric, and the mean and median are in the same location in the center of the box. In Figure 4.7, the boxplots summarize the quartile percentages and visualize the mean for each survey distribution. The quartiles in each boxplot are slightly symmetric. The pre-survey boxplot mean is affected by a single outlier that has a slight effect on the shape of the distribution. Although there is an outlier, the mean and median are in proximity. By contrast, the post-survey distribution does not have outlier(s) and the mean is located slightly to the left of the median. Both distributions have a slightly negative skew with the post-survey being more left skewed than the pre-survey. Both distributions means are less than the median with less variation of the mean and median in the pre-survey.

Figure 4.7

Participant TPACK survey averages (n=39)



Similarly, the normal quantile plots (labeled Normal Q-Q Plot) in Figures 4.8 and 4.9 compare the TPACK mean scores with quantiles of a theoretical normal distribution. These plots visualize how well the theoretical distribution models the empirical data. When the actual points and theoretical distributions (line on display) match, the points on the Q-Q plot will appear to show a reasonably normal distribution (Park, 2015). In the pre-survey Q-Q plot, (see Figure 4.8), the visualized outlier from the boxplot display shows as the single value deviating from the given straight line. The empirical data varies slightly from the display line. By contrast, the post-survey Q-Q plot (see Figure 4.9), does not display any points as outliers and there appears to have slightly more variation in the closeness of the observed empirical values to the theoretical normal distribution. Both, the pre- and post-surveys plot a reasonably straight line against the expected normal distribution suggesting a normal distribution.

Figure 4.8

Q-Q Plot of TPACK Pre-Survey

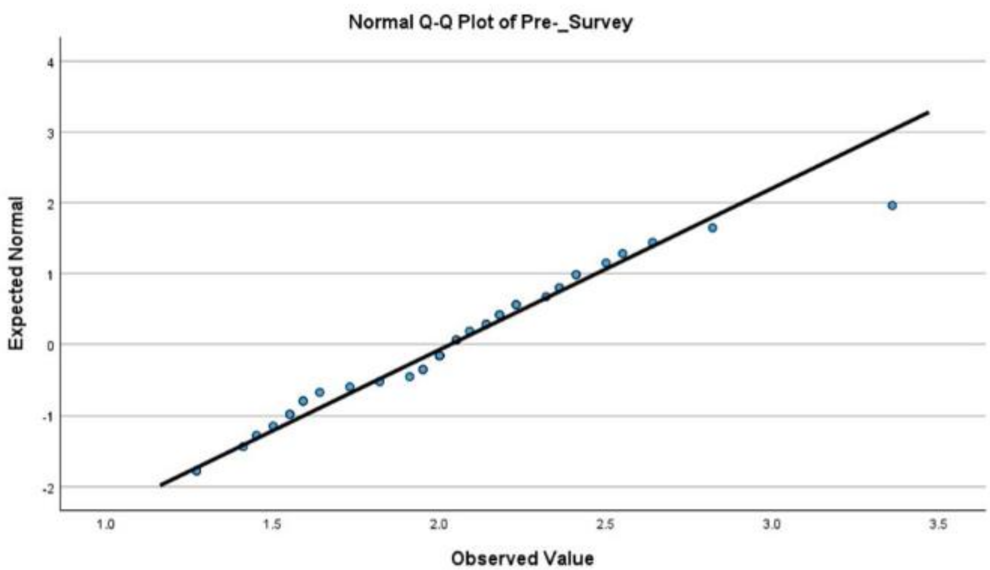
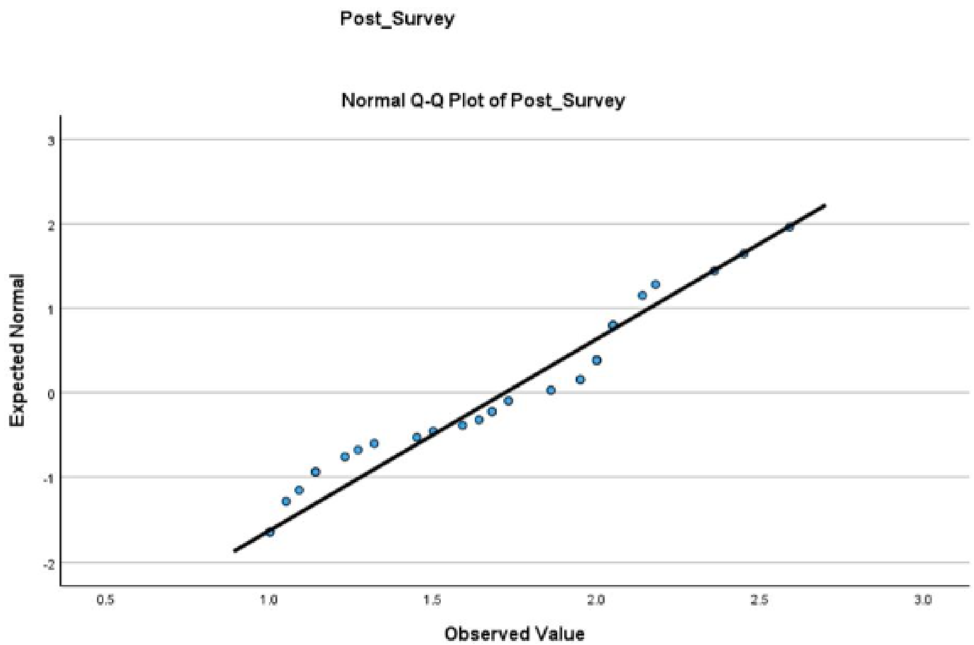


Figure 4.9

Q-Q Plot of TPACK Post-Survey



To support graphical methods of normality assumption, more formal testing was conducted on the TPACK survey data. Current research trends indicate that researchers either use the formal methods of skewness and kurtosis or Shapiro-Wilk testing to indicate normality (Demir, Saatcioglu, & Imrol, 2016; Orcan, 2020). Skewness, kurtosis, and Shapiro-Wilk numerical methods were calculated and analyzed for each survey to support the graphical findings for normality.

Skewness values measure the level of asymmetry of a distribution. From a visual perspective, data that is clustered to the left at the lower values suggest a positive skewness while values that are clustered at the high end on the right side of the graph indicate a negative skewness (Pallant, 2020). Negative values for skewness represent a tail on the left side of the distribution and positive values for skewness represent a tail on the right side of the distribution.

From a numerical perspective, skewness values of zero or in the proximity of zero (i.e., absolute value of one) indicate symmetrical distributions (Hatem, Zeidan, Goossens, Moreira, 2022; Park, 2015).

Kurtosis values measure "the extent to which the density of observations differs from the probability densities of the normal curve" (Hopkins & Weeks, 1990, p. 723). Graphically, kurtosis values that are high or positive have heavier tails and possible outliers, whereas negative kurtosis values that are low or negative have lighter tails and no outliers. From the numerical aspect, data that have kurtosis values of less than three indicate the assumption of normality in a distribution (Park, 2015).

Based on the empirical data collected, skewness and kurtosis indicate how the distribution of survey means for each TPACK survey question deviates from the normal distribution. Accordingly, a normal distribution should have skewness values between -1 and 1 while kurtosis values should be less than three (Park, 2015). In table 4.11, skewness on the pre-TPACK survey ranged from 0.02 to 1.73 and post-TPACK survey skewness were from -0.17 to 0.90. Kurtosis values on the pre-TPACK survey were from -0.41 to 3.75 while the post-TPACK survey values ranged from -2.08 to 1.91. Considering values across the entire distribution of both surveys indicate an assumption of normality in relation to the shape of the distribution based on skewness and kurtosis.

Table 4.11

*TPACK Survey Descriptive Statistics by Question**

Item	Mean		SD		Skewness		Kurtosis	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Technological Knowledge (TK)								
Q1 I know how to solve my own technical difficulties	2.18	1.74	0.60	0.68	0.69	0.90	1.57	1.91
Q2 I can learn technology easily	1.77	1.54	0.63	0.56	0.88	0.33	3.01	-0.97
Q3 I keep up with important new technologies	2.18	1.87	0.76	0.73	0.45	0.21	0.30	-1.05
Q4 I frequently play around with the technology	2.00	1.72	0.76	0.69	0.76	0.43	0.98	-0.77
Q5 I know about a lot of different technologies	2.38	2.00	0.85	0.76	0.25	0.38	-0.39	-0.13
Q6 I have the technical skills I need to use technology	2.10	1.79	0.68	0.62	0.40	0.14	0.63	-0.39
Content Knowledge (CK)								
Q7 I have sufficient knowledge about mathematics	1.85	1.62	0.59	0.54	0.02	0.03	-0.07	-0.98
Q8 I have various strategies for developing my understanding of mathematics	1.85	1.67	0.63	0.58	0.79	0.16	2.66	-0.60
Q9 I know about various examples of how mathematics applies in the real world	1.87	1.79	0.70	0.61	1.17	0.14	3.14	-0.39
Q10 I have a deep and wide understanding of algebra	1.85	1.72	0.88	0.69	1.56	0.43	3.75	-0.77
Q11 I have a deep and wide understanding of geometry	1.90	1.85	0.75	0.67	0.56	0.19	0.20	-0.69

Continued next page

Table 4.11 (continued)

Pedagogical Knowledge (PK)								
Q12 I know how to assess student performance in a classroom	1.79	1.62	0.62	0.59	0.14	0.34	-0.39	-0.65
Q13 I can adapt my teaching based upon what students currently understand or do not understand	1.74	1.46	0.60	0.51	0.13	0.16	-0.41	-2.08
Q14 I can adapt my teaching style to different learners	1.85	1.59	0.63	0.55	0.12	0.13	-0.41	-1.00
Q15 I can assess student learning in multiple ways	1.92	1.67	0.74	0.58	0.95	0.16	1.75	-0.60
Q16 I can use a wide range of teaching approaches in a classroom setting	1.92	1.72	0.81	0.65	0.78	0.34	0.57	-0.63
Technological Pedagogical Content Knowledge (TPACK)								
Q17 I can use strategies that combine mathematics, technologies, and teaching approaches that I learned about in my coursework in my classroom	2.10	1.77	0.79	0.54	0.83	-0.17	0.95	-0.08
Q18 I can choose technologies that enhance the mathematics for a lesson	2.26	1.77	0.79	0.63	0.53	0.20	0.24	-0.50
Q19 I can select technologies to use in my classroom that enhance what I teach, how I teach, and what students learn	2.13	1.77	0.77	0.63	0.51	0.20	0.36	-0.50
Q20 I can teach lessons that appropriately combine mathematics, technologies, and teaching approaches	2.15	1.67	0.71	0.53	0.71	-0.17	1.11	-0.82
Q21 I can teach lessons that appropriately combine algebra, technologies, and teaching approaches	2.36	1.74	0.74	0.68	1.73	0.36	3.67	-0.75
Q22 I can teach lessons that appropriately combine geometry, technologies, and teaching approaches	2.54	1.72	0.76	0.69	1.02	0.43	1.84	-0.77

***Note:** Scores for TPACK survey items scaled responses are in reverse order from a typical Likert scale. The responses for this study are (1) Strongly agree (2) Agree; (3) Neither agree nor disagree; (4) Disagree; (5) Strongly disagree.

To further evaluate the normalcy of the TPACK surveys data, the Shapiro-Wilk (SW) test was conducted. The Shapiro-Wilk test is typically employed when sample sizes are relatively small (n < 2000) due to its high statistical power (Demir et. al, 2016; Orcan, 2020; Park, 2015). The test statistic *(W*) that determines normalcy of the distribution lies between the values of zero and one. Smaller values indicate a rejection of normality and large values close to one indicate the data is normal (Razali & Wah, 2011). SPSS also provided the skewness and kurtosis for the pre- and post- TPACK survey for all 22 questions across knowledge domains. The skewness values for pre- and post- were 0.509 and -0.221, respectively and kurtosis was calculated at 0.951 and -0.967. In regard to the Shapiro-Wilk test, both TPACK surveys had test statistics close to one with the pre-survey statistic measuring 0.966 and post-survey at 0.930. More importantly, the *p*-values were greater than significance level 0.05 for both surveys (0.277 and 0.058), so these measures further supported the assumption of normality in the TPACK surveys scores.

Table 4.12

Normality Test for TPACK Survey

Item	Min	Med	Max	Skewness	Kurtosis	Shapiro-Wilk		
						Statistic	df	Sig.
Pre-Survey	1.27	2.05	3.36	0.509	0.951	0.966	39	0.277
Post-Survey	1.00	1.86	2.59	-0.221	-0.967	0.930	39	0.058

Descriptive statistics were calculated for each TPACK survey question. Within the TPACK survey, six items measure technological knowledge (TK), five items measure content knowledge (CK), five items measure pedagogical knowledge (PK), and six items measure technological pedagogical content knowledge (TPACK). Scores for TPACK survey items scaled responses for this study were in reverse order from a typical Likert scale. Typically, responses are scaled from (1) Strongly disagree to (5) Strongly agree. In this survey (see note in Table 4.11), items had scaled responses from one through five with one indicating strongly agree and five indicating strongly disagree. Using the SPSS software program, descriptive statistics (see Table 4.11) for each survey item per domain is listed. Across all four domains the pre-survey scores ranged from 1.74 to 2.54 and the post-survey scores had a range of 1.46 to 2.00. Table 4.13 provides summary statistics for the surveys. The mean and standard deviation for each knowledge domain decreased with the exception of TK where the standard deviation increased marginally. The greatest means decrease was in the TPACK domain, and the least means decrease was found in the CK domain.

Table 4.13

Active Participant Descriptive Results by TPACK Construct (n = 39)

Subtest	Pre-	SD	Post-	SD	Difference of Means
TK	2.10	0.54	1.78	0.55	0.32
CK	1.86	0.58	1.73	0.53	0.13
PK	1.85	0.59	1.61	0.50	0.24
TPACK	2.26	0.63	1.74	0.51	0.52

Technological Knowledge (TK). In the technological knowledge domain, pre-survey scores ranged from 1.77 to 2.38 while post-survey scores ranged from 1.54 to 2.00. The survey item that had the greatest difference in pre- and post-score means was question one: *I know how* *to solve my own technical difficulties.* The mean difference was 0.44 with 76.9% of participants selecting agree or strongly agree on the pre-survey and 92.3% selecting agree or strongly agree on the post-survey. Interestingly, 8% of participants strongly agreed with the survey item on the pre-survey while 36% strongly agreed on the post-survey. This is an indication that between the surveys participants learned how to access and troubleshoot technology issues (i.e., navigating new technologies). The survey item having the least difference of means was question two: *I can learn technology easily.* The mean difference between surveys was 0.23 with 94.8% selecting agree or strongly agree for the pre-survey and 97.4% selecting agree or strongly agree on the post-survey. Notably, the percentage of participants that selected strongly agreed increased from 31% to 49% during the professional learning course. Across the domain, the means of items had an average difference of 0.33 indicating that participants technological knowledge increased.

Content Knowledge (CK). In the content knowledge domain pre-survey scores ranged from 1.85 to 1.90 and post-survey scores were from 1.62 to 1.85. The survey item with the greatest difference in pre- and post-score means was question seven: *I have sufficient knowledge of mathematics.* The mean difference was 0.23 with 89.7% of participants selecting agree or strongly agree on the pre-survey while 97.4% selecting the same responses on the post-survey. Similar to question one, there was a 25% increase in participants selecting strongly agree from pre- to post- survey. Overall, going into the professional learning course, participants self-reported that they were confident in their field-specific knowledge and the subject matter being taught in the area of mathematics (i.e., applying quadratic formula). The least means difference was from survey item eleven: *I have a deep and wide understanding of geometry*. The mean difference between surveys was 0.05 with 82.1% selecting agree or strongly agree for the pre-survey and 84.6% selecting agree or strongly agree on the post-survey. The same percentage of participants selected strongly agree on both surveys (31%) while the slight increase was a result of two participants moving from disagree to neither and neither to agree. Across the content knowledge domain, items means had an average difference of 0.13 indicating there was a slight increase in content knowledge of participants. Additionally, the content knowledge domain experienced the least increase in means differences across all domains.

Pedagogical Knowledge (PK). The pedagogical knowledge item pre-survey scores were from 1.74 to 1.92 while the post-survey scores ranged from 1.46 to 1.72. The survey item that had the greatest difference in pre- and post-score means was question thirteen: *I can adapt my teaching based upon what students currently understand or do not understand.* The mean difference between the surveys was 0.28 with 92.3% of participants selecting agree or strongly agree on this item on the pre-survey and 100.0% selecting agree or strongly agree on the post-survey. The percentage of participants that chose strongly agreed on the pre-survey was 33.3% compared to 53.8% on the post-survey. These gains suggest that participants have an increased awareness and understanding of teaching strategies tailored to meeting students individual learning needs based on those students' prior knowledge. In the pedagogical knowledge domain, the least difference of means was found to be survey item 12: *I know how to assess student performance in the classroom.* The mean difference between pre- and post-surveys was 0.17 with 89.7% selecting agree or strongly agree for the pre-survey and 94.5% selecting agree or strongly agree on the post-survey. Similar to the technology and content knowledge domains, the percentage of participants that selected strongly agreed increased from 28.2% to 41.0% in the pedagogical knowledge domain. Across survey items 12-16, the difference of means average was 0.23 indicating a gain in participants pedagogical knowledge.

Technological Pedagogical Content Knowledge (TPACK). In the technological pedagogical content knowledge domain had pre-survey scores from 2.10 to 2.54 and the post-survey scores were from 1.72 to 1.77. The survey item that had the most significant change in pre- and post-score means was question twenty-two: *I can teach lessons that appropriately combine geometry, technologies, and teaching approaches.* The mean difference was 0.82 with 53.8% of participants selecting agree or strongly agree on the pre-survey and 87.2% selecting agree or strongly agree on the post-survey. The percentage of participants that strongly agreed went up from 2.6% on the pre-survey to 41.0% on the post-survey. This is a strong indicator that surveys participants were more confident in knowing how to align their pedagogical approaches with the appropriate technology tools (i.e., GeoGebra) to achieve desired student learning outcomes. Additionally, 7.7% initially responded that they disagreed or strongly disagreed with their ability to teach lessons that effectively integrate geometry content, appropriate technology, and applicable pedagogy while no participants selected disagree or strongly disagree on the post-survey. Survey item seventeen: *I can use strategies that combine mathematics, technologies, and teaching approaches that I learned about in my coursework in my classroom*, had the least significant change in the TPACK domain at 0.33 with pre-survey results showing 79.5% selecting agree or strongly agree and 94.8% choosing the same responses on the post-survey. Although this survey item had the least significant change in this domain, the difference of means was still greater than fourteen of the sixteen questions that comprised the TK, CK, and PK domains. Lastly, across the TPACK domain, the mean differences of the six items were the most significant of any domain at 0.52. This implies that the most significant impact of the professional learning experience supported participants knowledge of how to teach by combining their content knowledge with effective pedagogical techniques, and relevant technology tools to create opportunities that encourage student learning.

Overall, post-survey scores (see Table 4.11) were lower than pre-survey scores across all knowledge domains after participants completed the professional learning course. The next set of analysis conducted was to determine whether there was a statistically significant difference (at the $p < 0.05$ level) in the pre-and post- surveys. Additionally, if there was a statistical difference (at the $p < 0.05$ level), effect size was calculated to measure the magnitude of the differences between the survey scores (Ferguson, 2016).

Effect Size Measures. To further assess the importance of the differences that were evident in lower post-survey scores, the effect sizes were calculated for the remaining analysis of research question two. In this study, effect size addresses the magnitude of the difference between pre-TPACK and post-TPACK survey scores (Sullivan & Feinn, 2012). Additionally, the aim of research question two is to examine the effect of highly active participation in the *TMT* MOOC-Ed. Given that effect size quantifies the size difference between two groups (i.e., pre-, and post- survey scores), this is a more robust measure of the significance of differences (Coe, 2002; Sullivan & Feinn, 2012). Moreover, Sullivan and Fein (2012) argue that effect size is the most relevant finding of a quantitative study due to the limitations of p-value simply informing whether an effect exists while not revealing the size of the effect. Cohen's *d* was the statistical measure used to examine effect size (Cohen, 1988). Cohen's *d* is the most relevant effect size measure for this study given the nature of the data in presenting the differences between pre- and post- measures from the same group of participants in relation to standard deviation units. Effect size values range from 0 to 1 where coefficients between 0.20 and 0.49 represent a small effect size, from 0.50 to 0.79 describe a medium effect size, and effect sizes equal to or greater than 0.80 suggest a large effect size. Effect sizes are equivalent to a z-score of the standard normal distribution. A medium effect size of 0.53 is interpreted as the average score on the post-TPACK survey is 0.53 standard deviations above the average score of the pre-TPACK survey meaning that post-survey scores exceeded 52% of pre-survey scores (Coe, 2002).

The results in Table 4.14 provide aggregate inferential statistics for both surveys for all thirty-nine participants. A paired samples *t*-test was conducted with the SPSS statistical software program to determine if there was a statistical difference in the mean scores of the pre- and post-TPACK surveys. Results show there was a statistically significant decrease in TPACK scores from the time participants completed the pre-survey (M = 2.03, SD = 0.44) to the conclusion of unit five when the post-survey was completed (M= 1.72, SD = 0.44), t (38) = 4.05, p < 0.001 (two tailed). The mean decrease in survey scores was 0.31, with a 95% confidence interval ranging from 0.16 to 0.47. The Cohen's *d* statistic (0.65) indicates a medium effect size (Cohen, 1988).

Table 4.14

Active Participants Paired Differences Test and Effect Size (n = 39)

Mean		Difference of Means	SD	*t*	*df*	Effect Size
Pre-	Post-					
2.03 (0.44)	1.72 (0.44)	0.31	0.48	4.046***	38	0.65

Note: Standard deviations appear in parenthesis. Cohen's *d* uses the standard deviation of the mean differences ***p < 0.001

Next, I examined each knowledge domain to better understand how each construct contributed to participants overall change in their self-reported TPACK after the professional learning course. Four independent paired sample *t*-tests were conducted on the TPACK knowledge constructs. Table 4.15 shows the results from the four paired sample *t*-tests conducted on the TPACK surveys categorized by knowledge domain. The results indicate that there was statistically significant differences in pre- and post-scores in the TK, PK, and TPACK domains. In the technological domain, the pre-survey (M = 2.10, SD = 0.54) and post-survey (M = 1.78, SD = 0.55) had a means difference of 0.32 with $t\ (38) = 3.61$, $p < 0.001$ (two-tailed). Cohen's *d* statistic presented a medium effect size at 0.58. The pedagogical knowledge domain pre-survey (M = 1.85, SD = 0.59) and post-survey (M = 1.61, SD = 0.50) had a means difference of 0.24 with $t\ (38) = 2.531$, $p = 0.008$ (two-tailed). There was a small effective size (0.41) within the PK domain. In the TPACK domain, the pre-survey had the greatest mean of all domains (M = 2.26, SD = 0.63) and the post-survey results (M = 1.74, SD = 0.51) resulted in the greatest means difference of 0.52 with $t\ (38) = 4.753$, $p < 0.001$ (two-tailed). Subsequently, the TPACK Cohen *d* statistic of 0.76 indicated a comparably large effect size. The content knowledge domain pre-survey (M = 1.86, SD = 0.58) and post-survey (M= 1.73, SD = 0.53) had a means difference of 0.13 with $t\ (38) = 1.602$, $p = 0.059$ (two-tailed). Although there was no statistically significant difference in CK surveys, there was a decrease in mean scores and Cohen's *d* statistic determined a small effect size (0.26). To understand these results more fully, statistical significance is determined by *p*-value which is influenced by sample size. However, calculation of effect size is independent of sample size and quantifies the magnitude of differences found.

Table 4.15

Active Participants Paired Testing by TPACK Knowledge Construct (n = 39)

Subtest	# of items	*t*	*df*	Effect Size
TK	6	3.608***	38	0.58
CK	5	1.602	38	0.26
PK	5	2.531**	38	0.41
TPACK	6	4.753***	38	0.76

*p < .05 **p < .01 ***p < .001

To determine what effect participation in the *TMT MOOC*-Ed professional learning course had on highly active learners self-reported TPACK, summary statistics (mean, standard deviation, skewness, and kurtosis) were calculated on these participants (n = 10) as a subset of the 39 participants. Skewness values for pre- and post- surveys were -0.910 and -0.877, respectively, while kurtosis values were calculated as 0.340 and 2.174. Skewness and kurtosis levels for surveys were within appropriate parameters for parametric testing to be conducted (Ghasemi & Zahediasl, 2012). The Shapiro-Wilk normality test was also conducted to reinforce the summary statistics findings. The test had significance levels of 0.615 for the pre- survey and 0.473 for the post- survey. These results confirmed that both the pre- and post- surveys followed a normal distribution ensuring parametric testing were correct for the smaller sample size of less than 30.

A paired samples *t*-test was conducted with the SPSS statistical software program to determine if there was a statistical difference in the overall mean scores of the pre- and post- TPACK surveys of highly active participants. In table 4.16 results show there was not a statistically significant decrease in TPACK scores from the time participants completed the pre-survey (M = 2.03, SD = 0.45) to the when the post-survey was completed (M= 1.90, SD = 0.35), t (9) = 1.47, p = 0.18 (two tailed). However, the Cohen's *d* statistic (0.47) indicates a medium effect size (Cohen, 1988). Although the findings show that there is no statistical significance in TPACK survey scores in relation to *p*-value, there is substantive significance in those scores given the magnitude of the difference in scores as determined by the medium effect size (Coe, 2002; Fritz, Morris, & Richler, 2012; Sullivan & Feinn, 2012).

Table 4.16

Highly Active Participants Paired Differences Test and Effect Size (n = 10)

Mean		Difference of Means	SD	*t*	*df*	*p*	Effect Size
Pre-	Post-						
2.03 (0.45)	1.90 (0.35)	0.13	0.29	1.470	9	0.18	0.47

*p < .05 Cohen's *d* uses the standard deviation of the mean differences

To further explore TPACK survey results from highly active participants, summary statistics were calculated for each knowledge domain and paired sample *t*-testing was completed to determine statistical significance and effect sizes. Table 4.17 provides pre- and post- survey mean values and the differences in averages. The descriptive results indicate that highly active participants reported having the lowest level of technology knowledge on the pre-survey and higher average scores for pedagogical knowledge and content knowledge. Overall, the mean response for the technology domain decreased from 2.25 (SD = 0.64) to 2.03 (SD = 0.41) on the post-survey. Across both surveys in the technology domain, participants reported a negative effect in responses for keeping up with recent technologies (difference of -0.10) and the greatest positive effect in responses were from knowing a lot about different types of technologies (difference of 0.50). In the content knowledge domain, participants had an average score of 1.78 (SD = 0.60) on the pre-survey and 1.84 (SD = 0.49) on the post survey with a difference of means of -0.06. Highly active participants reported that their mathematical content knowledge decreased over the duration of the *TMT* MOOC-Ed. Questions pertaining to deep understanding in algebra and geometry and how mathematics is applicable in real-world contexts were consistent across both surveys. However, post-survey results indicate participants average scores had a slight increase when asked about sufficient knowledge of mathematics and diverse strategies for developing mathematics understanding.

Similar to the content knowledge domain, pedagogical knowledge scores averaged 1.78 (SD = 0.51) on the pre-survey and 1.74 (SD = 0.41) on the post survey. There was a slight decrease in average mean scores of 0.04. Participants reported greater understanding in the areas of assessing student performance in the classroom and adapting teaching to accommodate different learners. Additionally, there was improvement in pedagogical knowledge regarding assessing student learning in multiple ways. According to pre-survey scores, knowledge of mathematical content and pedagogical knowledge tied for the lowest score of all domains. This can be interpreted as highly active participants started the professional learning course with adequate content knowledge and pedagogical knowledge. As a result, there were either slight or no substantive gains in these particular domains.

Overall, the TPACK domain, which combines all three knowledge constructs, had the greatest knowledge gains from pre- to post- survey. In this domain the pre-TPACK survey had an average score of 2.13 (SD = 0.52) while the post-survey average of 1.89 (SD = 0.41) revealed the greatest difference of average scores (0.24). Participants expressed increased understanding of choosing technologies that enhanced mathematics lessons and selecting appropriate technologies to support their teaching and student learning. They also reported gains in how to teach lessons that combine mathematics content (i.e., algebra and statistics) with applicable technologies and adaptive pedagogical approaches to support students mathematical learning. The most prominent increase across all TPACK constructs was in this domain with an average difference of 0.6 between pre- and post- TPACK scores. Highly active participants reported that they could teach lessons that combined geometry, technologies, and teaching approaches in the classroom.

In summary, overall post-TPACK survey scores were lower than the pre-TPACK survey scores. The TPACK knowledge of highly active participants in the *TMT* MOOC-Ed increased over the duration of the professional learning course. Pre- survey scores ranged from 1.9 to 2.6 on the pre-survey to 1.7 to 2.0 on the post- survey. Of the three knowledge constructs, participants noted a positive difference in averages in the TK, PK, and TPACK domains. Highly active participants reported high mathematical content knowledge on the pre- survey resulting in minimal changes in this domain during the extent of the course.

Table 4.17

Highly Active Participant Descriptive Results by TPACK Construct (n = 10)

Subtest	Pre-	SD	Post-	SD	Difference of Means
TK	2.25	0.64	2.03	0.41	0.22
CK	1.78	0.60	1.84	0.49	-0.06
PK	1.78	0.51	1.74	0.41	0.04
TPACK	2.13	0.52	1.89	0.41	0.24

The last set of analysis conducted was to better ascertain the actual effect sizes of each knowledge construct of the highly active learner participants. Table 4.18 depicts results from the paired sample *t*-test analysis of the TPACK surveys by knowledge domain. Although there was a positive difference in means from the pre- and post- survey scores, results concluded no statistically significant differences in scores in the technological domain (t (9) = 1.381, p = 0.201) and pedagogical domain (t (9) = 0.361, p = 0.726). The Cohen's *d* statistic for the technological domain (0.44) calculated a small effect size while the pedagogical domain effect size (0.11) showed no substantive significance. The content knowledge (t (9) = -0.461, p = 0.656) TPACK construct showed a reversal in the directionality of the effect with Cohen's *d* statistic of -0.15. As discussed in the previous section, this finding could be a result of highly active participants prior experiences with mathematics content knowledge considering 70% held advanced degrees and were experienced teachers with an average of 19.9 years of teaching.

Table 4.18

Highly Active Participants Paired Testing by TPACK Knowledge Construct (n = 10)

Subtest	# of items	*t*	*df*	*p*	Effect Size
TK	6	1.381	9	0.201	0.44
CK	5	-0.461	9	0.656	-0.15
PK	5	0.361	9	0.726	0.11
TPACK	6	2.627*	9	0.027	0.83

*p < .05 Cohen's *d* uses the standard deviation of the mean differences

Similar to the findings of all 39 participants, there was a statistically significant difference in survey scores in the TPACK domain (t (9) = 2.627, p = 0.027) of highly active participants.

Moreover, the Cohen's *d* statistic of 0.83 showed a large effect size in this domain. Highly active participants reported that the greatest effect of their professional learning experience was increased knowledge of combining pedagogical techniques and technological tools to enhance student learning of mathematics.

Integrated Analysis for Research Question 3

This dissertation research study employed a concurrent embedded mixed methods design (QUAN + QUAL) where qualitative and quantitative data were given equal weight. Both quantitative and qualitative data were collected and analyzed separately then the data was mixed for analysis. Integrated data analysis for this section addressed the third research question for this study: *What is the nature of the relationship between highly active teacher learners' TPACK and their modes of discussion in the Teaching Mathematics with Technology MOOC-Ed?*

This mixed-methods research held to a convergence model of data collection and analysis of findings. Data collection and analysis for both research questions one and two occurred at the same time for the surveys and forum postings for all participants. More specifically, quantitative data collection was initiated when active teacher participants completed a pre-TPACK survey after enrollment in the *TMT* MOOC-Ed course to establish a criterion score prior to participation in the professional learning course. A post-TPACK survey was administered at the conclusion of the course to ascertain the self-reported TPACK growth experienced during the five-week intervention. While actively immersed in the course, teacher learners posted original contributions and replied to other participants in discussion forums while engaging with course resources and technology tools. Qualitative measures of line-by-line content analysis were conducted on discussion forums to ascertain the nature of the teacher learners' forum contributions. Table 4.19 includes findings from research question one and two. In relation to discussion forums analysis showed that as teacher learners' progressed from unit to unit, there was an increase in postings that discussed to critique, discussed to construct knowledge, and discussion that shared improved understanding. For research question two, statistical testing showed that highly active teacher learners TPACK increased in several knowledge domains and the greatest gains were experienced in the TPACK domain.

Table 4.19

Qualitative and Quantitative Findings from RQ1 and RQ2

Qualitative Data and Analysis	Quantitative Data and Analysis
	Data analysis supports the finding that there was a medium effect size in overall TPACK knowledge growth for highly active teacher learners.
Data analysis supports that the frequency of forum contributions categorized as discussing to critique, construct knowledge, and share improved understanding increased among highly active teacher learners during the *TMT* MOOC-Ed course while discussions that comprehend decreased.	Data analysis showed from pre- to post- TPACK survey a small effect size in the pedagogical knowledge domain and medium effect size in the technological domain of highly active teacher learners. Data analysis showed statistically significant gains from pre- to post- survey in the TPACK domain. These results also showed a large effect size for highly active teacher learners.

In this concluding section of analysis, research question three is addressed. Data from research question one and research question two was integrated through merging and joint-table matrix display for analysis and comparison. This point of integrating qualitative and quantitative data sources was intended to investigate emerging patterns and potential relationships between teacher learners TPACK knowledge and their modes of discussion. Figure 4.10 shows the organization of research question three and the data collected and analyzed to inform the data integration process of addressing the relationships (if any) between highly active teacher learners' TPACK knowledge and their modes of interaction with other participants in the discussion forums.

Numerous research studies have noted that responses to online discussion forum prompts do not automatically elicit higher levels of thinking that encourage construction of knowledge and synthesizing of ideas that improve participants' understanding. Additionally, studies have found that frequent and continuous forum engagement contributes to higher achievement and growth in understanding. For these reasons, the analysis for research question three will focus on two conjectures that address the *quantity* and the *quality* of discussion forum contributions.

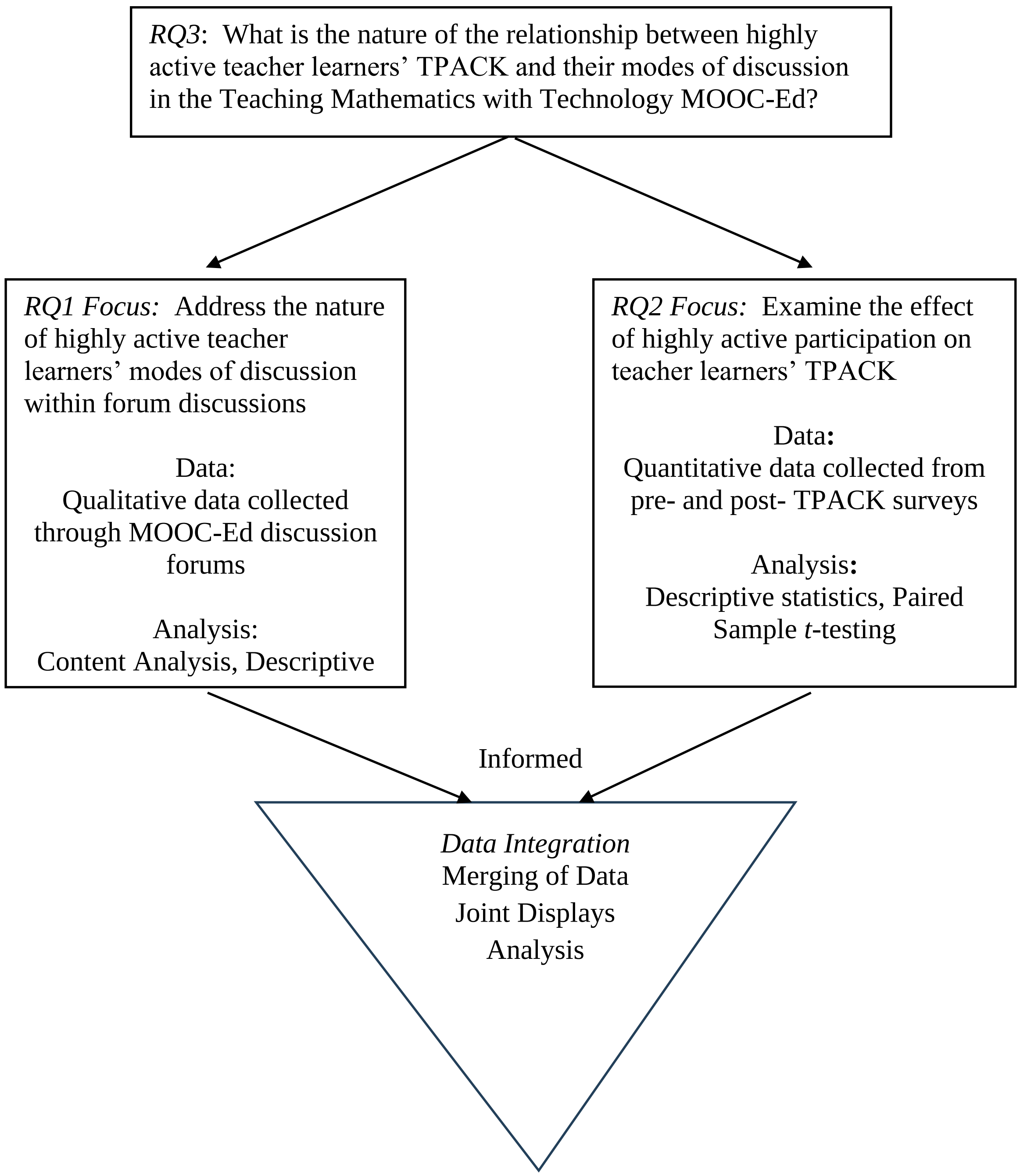
This study will reference these terms as the following:

- ***Quantity*** refers to the average number of posts (original or replies) made by a highly active teacher learner in four units during the five-week professional learning MOOC-Ed.
- ***Quality*** refers to the frequency of dispositions categorized by the four productive online discussion model dispositions listed as (1) discuss to comprehend, (2) discuss to critique, (3) discuss to construct knowledge, or (4) discuss to share improved understanding
- The two conjectures that guide the analysis of research question three examined the relationship between TPACK and discussion forum contributions through the attributes of quantity and quality. The first conjecture will explore the notion that participants who experienced more TPACK growth were hyper engaged in the discussion forums relative to their highly active peers. The second conjecture deals with the *quality* of discussion

forum postings beyond discussions that seek to only comprehend course materials and resources.

Figure 4.10

Research Question Three Analysis Flowchart



Conjecture 1: Quantity–Participants who had the greatest gains in TPACK were more actively involved (i.e., initiated discussions and replied to other users more frequently) as compared to other highly active teacher learners.

Conjecture 2: Quality–Participants who had forum postings coded with disposition two (Discuss to Critique) and disposition three (Discuss to Construct Knowledge) and disposition four (Discuss to Share Improved Understanding) at a greater frequency compared to other highly active teacher learners experienced the greatest gains in their TPACK knowledge.

Quantity as an Attribute of TPACK Knowledge Growth. To investigate conjecture one, qualitative and quantitative data was merged in a joint display to determine if the most active teacher learners experienced the greatest TPACK growth in the *TMT* MOOC-Ed. Table 4.20 lists the ten highly active teacher learners with average posts per unit and their individual TPACK scores, and the means difference between pre- and post- survey. This table has been organized to depict the average posts per unit in ascending order based on the frequency. Qualitative findings show that highly active teacher learners posted an average of 5.6 times per unit. Mark had the highest average number of posts per unit at 9.75 (39 total posts) while the teacher learner next to him posted while Sarah had the lowest average number of posts per unit at 3.75 (15 total posts). Overall, quantitative results indicate a decrease in TPACK survey means. Figure 4.11 provides a graphical representation of teacher learners' TPACK and highly active participant postings. From this scatterplot, we can see that there does not appear to be a meaningful relationship between the level of forum engagement of highly active teacher learners and their TPACK scores. To further investigate, SPSS statistical software was employed to calculate the Pearson correlation coefficient to quantify the relationship between the average number of posts per unit (as measured by the four-unit discussion forums) and difference of means (as measured by the pre- and post- TPACK surveys). Similar to research question two, preliminary analysis ensured there was no violation of the assumptions of normality. The analysis indicated that there was a weak negative correlation between the two variables, $r = -0.16$, $n = 10$, $p = 0.665$, with minimal association between the number of posts and the difference in means. Results indicate there was a nominal relationship between quantity of postings and teacher learners' TPACK growth.

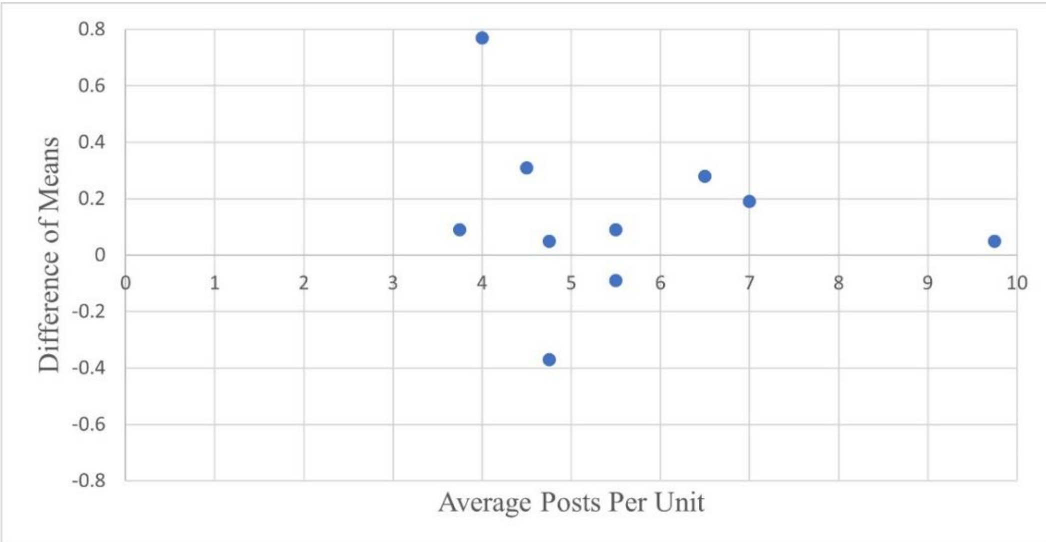
Table 4.20

Qualitative and Quantitative Joint Display for Quantity

Highly Active Teacher Learners	Avg Posts Per Unit	TPACK Mean		Difference of Means
		Pre	Post	
Sarah	3.75	1.82	1.73	0.09
Mike	4.00	2.82	2.05	0.77
Sal	4.50	1.45	1.14	0.31
Cory	4.75	2.05	2.00	0.05
Jessica	4.75	1.27	1.64	-0.37
Karen	5.50	2.05	2.14	-0.09
Jamie	5.50	2.09	2.00	0.09
Simon	6.50	2.14	1.86	0.28
Jane	7.00	2.14	1.95	0.19
Mark	9.75	2.50	2.45	0.05

Figure 4.11

Scatterplot Displaying Average Posts and Differences of TPACK Means--Quantity



Quality as an Attribute of TPACK Knowledge Growth. To investigate conjecture two, qualitative and quantitative data was integrated in a joint matrix display to explore the notion that teacher learners' who discussed to critique, construct knowledge, and share improved understanding at a greater frequency experienced more growth in TPACK knowledge. Table 4.21 includes the percentage of discussions coded and enumerated by disposition for each teacher learner. For example, Jane had 15 discussion forum posts that had 28 codes. Of those 28 codes, 68% were discussed to comprehend, 28% discuss to critique, and 4% discuss to construct knowledge and no forums coded as 'other'. Additionally, the display contains each knowledge construct from the TPACK framework and the increase (or decrease) in TPACK knowledge experienced from pre- to post- survey. The table was organized in descending order according to the gains that occurred in the TPACK domain. This was done to identify any emerging patterns or relationships that may exist between the two data sets. The table arrangement shows that eight of ten teacher learners increased their TPACK knowledge by a value of greater than 1.0. The gains in TPACK knowledge for ranged from 1.07 to 1.83 for these eight participants while two forum contributors (Jessica and Cory) experienced TPACK growth of 1.0 or less. Eight of the ten teacher learners had forum contributions that discussed to critique (D2), discussed to construct knowledge (D3), and discussed to share improved understanding (D4). All top eight teacher learners posted discussions that critiqued while four of those eight posted discussions that constructed knowledge with a single contributor (Mark) posting to share improved understanding. The two teacher learners who did not have any contributions outside of discussing to comprehend (D1) experienced the lowest TPACK knowledge gains (Jessica and Cory). Combined, they had a total of 33 discussion forum posts (38 codes) with 19 codes for discussing to comprehend and 19 coded as ‘other’. Figure 4.12 provides a graphical representation of highly active teacher learners’ cumulative percentage of discussion forums coded from D2-D4 and their corresponding TPACK gains. From this scatterplot, we can see that there appears to be a meaningful positive relationship between the percentage of forum contributions from D2 to D4 and highly active teacher learners reported TPACK growth.

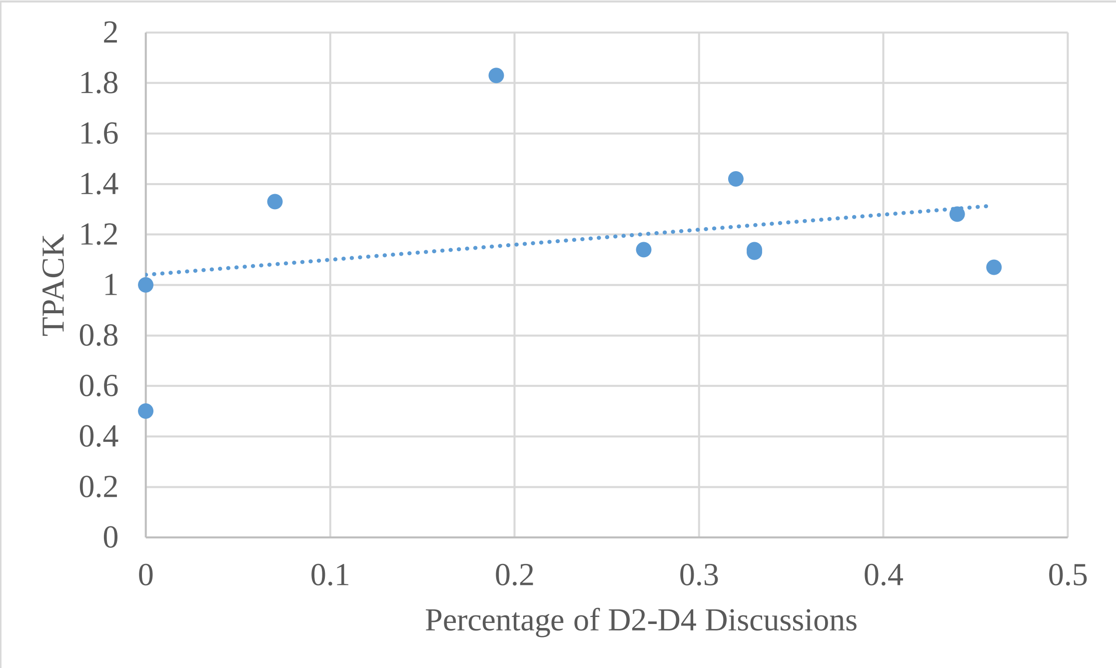
Table 4.21

Qualitative and Quantitative Joint Display for Quality

Highly Active Teacher Learners (total codes)	Productive Online Discussion Model Dispositions					TPACK Domains (Gain)			
	Comprehend	Critique	Construct Knowledge	Share Improved Understanding	Other	TK	CK	PK	TPACK
Mike (16)	0.75	0.19	0.00	0.00	0.06	1.50	0.40	0.00	1.83
Jane (28)	0.68	0.28	0.04	0.00	0.00	-0.17	0.00	0.00	1.42
Sarah (15)	0.93	0.07	0.00	0.00	0.00	-0.17	0.00	-0.60	1.33
Mark (39)	0.38	0.31	0.10	0.03	0.18	0.00	-0.20	0.20	1.28
Karen (22)	0.55	0.28	0.05	0.00	0.14	0.50	-1.00	0.00	1.14
Jamie (22)	0.73	0.27	0.00	0.00	0.00	0.00	0.20	0.00	1.14
Sal (18)	0.67	0.33	0.00	0.00	0.00	0.33	0.00	0.20	1.13
Simon (26)	0.54	0.27	0.19	0.00	0.00	0.00	0.40	0.80	1.07
Cory (19)	0.32	0.00	0.00	0.00	0.68	0.17	0.00	0.00	1.00
Jessica (19)	1.00	0.00	0.00	0.00	0.00	0.00	-0.40	-0.20	0.50

Figure 4.12

Scatterplot Displaying Percentage of D2-D4 Posts and TPACK Gains—Quality



Conclusion of Findings

Chapter four findings were presented for the research study on the modes of discussion for active and highly active teacher learners measured using the productive online discussion model, change in TPACK knowledge at the conclusion of the *TMT* MOOC-Ed measured using pre- and post- TPACK surveys, and the relationship (if any) between participants TPACK knowledge and modes of discussion using the attributes of quantity and quality to measure the nature of this relationship. Descriptive statistics were calculated for the types of discussions occurring in the discussion forums while inferential statistics was calculated to determine differences in overall TPACK knowledge and independent TPACK knowledge constructs.

Qualitative analysis for teacher learners modes of discussion included line-by-line content analysis on discussion forum contributions. Findings showed that during the course, active and highly active teacher learners posted in disposition one (discuss to comprehend) at a higher frequency than other dispositions. More importantly, findings indicated that as the course progressed, the percentage of postings that discussed to critique (D2), construct knowledge (D3), share improved understanding (D4) increased while discussions that sought to comprehend (D1) decreased across units.

Quantitative analysis consisted of paired-sample *t* testing on the pre- and post-TPACK surveys for active and highly active teacher learners. The difference of means score of 0.31 for all participants in TPACK knowledge indicated that there was significant differences in scores and participants experienced an increase in TPACK knowledge. Analysis also indicated there was significant differences in individual technological knowledge (TK), pedagogical knowledge (PK) and technological pedagogical content (TPACK) knowledge domains. No significant differences were found in the content knowledge (CK) domain. For highly active teacher learners, there was no significant difference in TPACK survey results, and no significant differences found in TK, CK, or PK. There were significant differences found in TPACK knowledge with a large effect size.

Integrated analysis combined both qualitative and quantitative data in joint displays to address two conjectures that focused on the quantity and quality of postings and their potential relationship each attribute had with highly active teacher learners TPACK knowledge. Findings indicated that there was no relationship between the quantity of forum contributions and TPACK knowledge gains. In relation to quality, findings showed that there was a positive relationship between the percentage of postings from D2 to D4 and highly active teacher learners increase in TPACK knowledge.

CHAPTER 5: DISCUSSION

Introduction

The purpose of this dissertation was to explore the nature of how highly active teacher learners engaged in the discussion forums and what effect their participation had on their TPACK knowledge while enrolled in a professional learning course for mathematics educators. This chapter begins with a summary of this dissertation research study. The second section includes a discussion of the findings from the research questions that guided this study. The third section provides limitations, implications of the findings, and suggestions for future research.

Summary of the Research Study

Teacher learning and professional learning are essential elements for teachers to strengthen pedagogical practices, enhance student outcomes, and improve schools (Bleicher, 2014; Borko, 2004). Over the last few decades, there has been numerous contexts that support formal and informal teacher learning. For example, school-based professional development, conferences, workshops, college courses, and summer programs are diverse venues that provide opportunities for teachers to learn (Borko, 2004; Desimone, 2009). Traditionally, teacher learning has been studied in the context of formal professional development (PD). More recently, the research community has advanced towards more sophisticated approaches to understanding teacher learning.

As student learning has trended towards online distance settings from face-to-face environments, mathematics teachers were compelled to become technologically competent in new ways of teaching and learning (Marpa, 2021). In turn, this has had a positive impact on mathematics teachers seeking professional development opportunities to serve the learning needs of their students. With the growing necessity for professional development, professional learning courses like MOOC-Eds afford educators the opportunity and flexibility to leverage these learning venues for their personal and professional learning. As these professional learning courses become more prevalent, it is advantageous for the research community to explore the potential impact that active participation can have on teachers' TPACK knowledge.

The intent of this concurrent embedded mixed methods research study was to explore the nature of how teacher learners' engaged in discussion forums and examine the relationship between their forum contributions and their TPACK knowledge. This study employed a (QUAN+QUAL) design that gave equal weight to quantitative and qualitative data (Johnson & Christensen, 2019). Qualitative and quantitative data were collected simultaneously at the beginning, during, and the conclusion of the five-week *TMT* MOOC-Ed professional learning course.

The quantitative data collection process was initiated with the 22-question TPACK survey developed and validated by Zelkowski, et al. (2013) and was available for participants to complete at the beginning of the course. The same survey was made accessible to participants in the last unit of the course to collect post TPACK survey scores. The five-point Likert survey instrument consisted of six technological knowledge (TK) items, five content knowledge (CK) items, five pedagogical knowledge (PK) items, and six technological pedagogical content knowledge (TPACK) items. The survey instrument was adopted to quantify the self-reported differences in TPACK growth of teacher learners identified as active participants in the discussion forums. SPSS statistical software was used for statistical testing and analysis. Normality testing was conducted for the active participants (n = 39) to evaluate assumptions of normality within and across knowledge domains to validate the use of parametric testing techniques. Descriptive statistics were collected including mean, standard deviation, skewness, and kurtosis for each survey item to determine the difference of means for specific knowledge domains. Inferential statistics, including paired-sample *t* testing was used to determine statistical significance and effect size of paired differences of means for the overall survey and individual knowledge constructs (TK, CK, PK, TPACK) on active participants and highly active participants.

The qualitative phase of this study, the nature of highly active teacher learners' modes of discussion within forums occurred during the five-week professional learning MOOC-Ed. Active teacher learners' were determined through criterion sampling (participants who completed pre- and post- TPACK surveys) as an informative strategy to identify participants who consistently posted at least once in each discussion forum. The productive online discussion model was adopted as an a priori coding framework to conduct line-by-line content analysis on discussion forum postings. The model identifies four discussion dispositions (comprehend, critique, construct knowledge, share improved understanding) and three specific learner actions for each disposition. Content analysis was conducted on 429 discussion forum contributions from all active learners (n = 39). Descriptive statistics including counts and frequencies of dispositions and learner actions. Data was compiled to ascertain a comprehensive view of dispositions per unit. Additionally, this analysis informed the intensity sampling procedure in determining the top 25% of forum contributors as highly active teacher learners (n = 10). Counts and frequencies of dispositions and learner actions were summarized from units one through four for active learners categorized as 'highly active.' Discussion forum postings were viewed in a summative format to determine trends in dispositions per unit and frequency of dispositions per unit. Qualitative analysis concluded with the types of discussions that occurred by units to further examine patterns and relationships between dispositions and learner actions and interactions between teacher learners.

In the interactive analysis phase of the study, two conjectures were formulated and the findings from research question one and research question two were combined to explore the relationship between highly active teacher learners TPACK and their discussion forum contributions. In the analytic process, data from both research questions were merged and displayed with joint tables to explore the attributes of quantity and quality of postings. Data including average posts per unit and differences in means were analyzed for quantity. Data analysis for quality included examining emerging patterns and trends across disaggregated dispositions and comparing and contrasting those frequencies to the differences in means of the TPACK knowledge constructs.

DISCUSSION OF RESEARCH FINDINGS

The purpose of this study was to answer the following research questions:

1. What is the nature of highly active teacher learners' modes of discussion within forum discussions in the Teaching Mathematics with Technology MOOC-Ed?
2. What effect does participation in the Teaching Mathematics with Technology MOOC-Ed have on highly active teacher learners' TPACK?
3. What is the nature of the relationship between highly active teacher learners' TPACK and their modes of discussion in the Teaching Mathematics with Technology MOOC-Ed?

In chapter four, results were analyzed using multiple data sources to answer the research questions that guided this study. In this section of chapter five, the findings from analysis are discussed.

Research Question One

Research question one examined the interactions of active and highly active learners in the Teaching Mathematics with Technology (*TMT*) MOOC-Ed discussion forums. To assess the extent of participant interactions, the productive online discussion model was utilized within and across forums. Overall contributions to the *TMT* Discussion forums showed 71.62% (n = 39) of total contributions were generated by active teacher learners' who completed the course while 22.70% (n = 111) were generated by other participants. For the thirty-nine participants, the distribution of forum postings were consistent across the four units and two forums (EE and CP) per unit with the greatest percentage of postings occurring in unit three. These findings are similar to those of Bonafini (2018b) who found that those participants who were active in the forums were consistent contributors and were the most influential participants throughout their MOOC-Ed experience. A number of authors have found that there were decreases in the quantity of forum posts as MOOCs have progressed (e.g., Onah et al., 2014, Brinton et al., 2014; Kizilcec, Piech, & Schneider, 2013; Thomas 2002). Most of these studies analyzed tutor-monitored discussion forums, whereas the discussion forums in the *TMT* MOOC-Ed were peer supported discussions where forum prompts encouraged learners to analyze student thinking, analyze tasks, reflect on their own task explorations, and share ideas and resources with their colleagues. The discussion forums within the *TMT* MOOC-Ed were designed for the participants to focus on course content (i.e., tasks, videos, activities) to enhance their own professional learning experiences. Additionally, content analysis of the discussion forums revealed that there was very little ‘social discussion’ that was generated, and forum contributions were mainly about course topics and addressing the forum prompts provided.

As the *TMT* MOOC-Ed progressed, the online discussion forums provided a collaborative space for meaningful discourse among highly active teacher learners. In a study analyzing higher order thinking in online forums, McLoughlin and Mynard (2009), found that most online student discussions were categorized as ‘exploration’ where students shared experiences and compared information. However, the percentage of posts coded as ‘integration’ suggests that students went beyond sharing and comparing. Postings coded as ‘integration’ and ‘resolution’ increased as the online course progressed indicating higher levels of thinking. Consistent with the finding of the McLoughlin and Mynard study, the patterns of engagement in the *TMT* forums continued to evolve from unit to unit. In unit one most forum contributions (76.3%) sought to comprehend by making connections to the course content and resources, making connections between the course content and what they had experienced in their classrooms, or relating their learning experiences to prior knowledge. Also, most participants posted an original thread and did not reply to other posts. In unit two through unit four the percentage of discussions that sought to critique, construct knowledge, and share improved knowledge increased while discussions centered on comprehension decreased. Unit two had 61.8% of posts, unit three had 62.1% of posts, while unit four had the least with 53.3% of discussions coded as discussing to comprehend. Furthermore, as the course progressed teacher learners’ postings referenced their peers’ forum postings, and this affirmed a collective knowledge around the MOOC content. Earlier studies have supported these findings in the *TMT* MOOC-Ed. Gao (2014) analyzed asynchronous online discussions in a graduate-level educational course and found that implementing the interaction analysis model as a strategy to foster meaningful participant interactions improved the quality of discussion between students. Kellogg et al., (2014) applied the interaction analysis model to assess the knowledge construction of participants and found most postings moved beyond sharing information and agreement to co-construction and synthesis of knowledge. However, a few posts moved into the fourth phase of modifying newfound knowledge and agreement on applying this knowledge.

Similarly, the findings of this dissertation study align with these earlier studies. Forum contributions that discussed to critique (built on or added ideas to colleagues posts and challenged the ideas or activities of the MOOC content) and discussed to construct knowledge (compare and contrast views from the MOOC content and colleagues postings, asking questions to facilitate thinking and discussion) increased in frequency as the course progressed. However, less than 2% of posts was coded as discussing to share improved understanding. The lack of forum contributions that discuss to construct knowledge and share improved understanding could be explained by the constraints of threaded discussion forums (Gao et al., 2013). This course was a five-week professional learning course where participants registered and started working on the course each day. Similar to other professional learning courses participants can register and start accessing course materials at any time. In the *TMT* MOOC-Ed participants were posting in unit four after several few weeks while other participants were initiating the registration process and posting in unit one. This makes having a focused and sustained discussion more difficult where unread postings and more recent forum contributions receive more attention and newer posts are more likely to be replied to than older posts. Also, the hierarchical structure of threaded forums may make it difficult to synthesize ideas and hinder convergent thinking. Rather than drawing forum contributions together, gathering around forward-thinking ideas, and creating a community of learners, the arrangement of expanding and branching conversations challenges consensus and community building.

Research Question Two

Research question two examined the self-reported TPACK of active and highly active teacher learners' at the onset and conclusion of the Teaching Mathematics with Technology (*TMT*) MOOC-Ed. Overall, active and highly active teacher learners' reported that their TPACK knowledge improved as a result of participating in the professional learning course. For all teacher learners' in this study, TPACK growth was found to be statistically significant with a medium effect size of 0.65.

More specifically, for the thirty-nine active participants, results from the pre- and post-TPACK surveys indicate that there was statistically significant growth in the technological knowledge (TK) domain, the pedagogical knowledge (PK) domain, and the technological pedagogical content knowledge (TPACK) domain. Also, the magnitude of the differences of means was found to have a medium to medium-large size effect for these three knowledge constructs. Of the TPACK construct, content knowledge was not found to be statistically significant. However, there was a positive difference of means that resulted in a small effect size. Brinkley-Etzkorn (2018) found comparable results when studying the effectiveness of faculty training development using TPACK. Analogous to this study, Brinkley-Etzkorn found that content knowledge scores were already high in the pre-survey assessment so the capacity for significant improvements were decreased. This may explain the lack of reported improvements in content knowledge.

Highly active teacher learners' were a subset of the active teacher learners' in this research study. Of the thirty-nine participants, ten were categorized as highly active due to their levels of engagement in the *TMT* MOOC-Ed discussion forums. For this group, overall TPACK growth was not found to be statistically significant. However, there was a positive difference in means and a medium effect size indicating that the professional learning course was effective in supporting participants TPACK growth. For the distinct TPACK knowledge constructs, highly active teacher learners experienced positive differences of means in the technological knowledge domain (TK), pedagogical knowledge domain (PK), and technological pedagogical content knowledge (TPACK) domain. In these domains there was also a range of effect sizes ranging from small to large meaning that the course was effective in strengthening highly active participants TPACK. Pedagogical knowledge (PK) had a small effect size at 0.11 and technological knowledge (TK) had a medium effect size of 0.48. Technological pedagogical content knowledge (TPACK) had the greatest effect size at 0.83 and the difference in means for this domain was also found to be significant.

The most sophisticated knowledge domain is the intersection of the three domains (TK, CK, and PK) forming technological pedagogical content knowledge (TPACK). These questions reference combining appropriate technologies and pedagogical practices with specific subject matter to teach effective lessons that impact student learning. Mentioned earlier, highly active teacher learners reported significant changes in TPACK with a large effect size. The *TMT* MOOC-Ed was developed with four integrated design principles (multiple voices, self-directed learning, peer-supported learning, and job-connected learning). Each principle includes instructional elements (i.e., expert panels, resource collections, asynchronous discussions, student scenarios, peer feedback, practice-related activities) that were included in the *TMT*

MOOC-Ed. Just as important, the didactic tetrahedron guiding framework employed to develop the *TMT* MOOC-Ed emphasizes the interaction between teachers, students, mathematics and technology with pedagogical activities as an anchor connecting all four vertices impact participant learning outcomes (Hollebrands, 2017). The intentional course design principles, embedded instructional elements, and guiding framework influenced the integrated TPACK learning of MOOC-Ed participants (Dede et al., 2016; Hollebrands & Lee, 2020). Mouza et al., (2014) had similar findings for participants in an integrated pedagogical course for pre-service teachers that focused on TPACK growth.

The study reported a negative difference of means in the content knowledge (CK) domain. Content knowledge questions on the TPACK pre-survey averaged 1.78 while the average was 1.84 on the post-survey. This may be explained by supplemental findings from the research study. Similar to Bonafini (2018a), highly active teacher learners in this study were also experienced teachers. The participants were experienced teachers with an average of 19.9 years of teaching experience. Excluding a single teacher learner with two years' experience, the remaining nine participants averaged 21.8 years of teaching experience. It is likely that most of their knowledge about what they teach, and their knowledge of subject matter was acquired prior to participating in the *TMT* MOOC-Ed (Brinkley-Etzkorn, 2018). Additionally, the objectives of this MOOC-Ed did not focus on developing teachers content knowledge. The purpose of this course was for teachers to successfully integrate technology tools in the classrooms of middle and high school teachers in a way that enhanced student learning and mathematical thinking.

In reference to the small effect size experienced in the pedagogical knowledge construct, it can be assumed that the beginning of the participants teaching careers were exclusively synchronous instruction in face-to-face settings allowing time for pedagogical skills to be developed (Shulman, 1987). These participants started the MOOC-Ed with numerous years of teaching substantiated by writing and implementing lesson plans, using instructional strategies to teach subject matter, and assessing student learning. Analogous to the findings of Bonafini (2018b), highly active teacher learners in the course were also highly qualified teachers. Seven of the ten highly active learners held advanced degrees with six holding master's degrees and one with a PhD, further emphasizing that educational and teaching experience were factors that influenced change (or lack) in TPACK knowledge during the professional learning course.

Research Question Three

Research question three examined the nature of the relationship between highly active teacher learners' TPACK and their modes of discussion. Integrated analysis using qualitative and quantitative findings for this research study was framed using two conjectures focusing on quantity and quality. Quantity addressed the relationship between the number of posts and participant TPACK growth. Kew and Tasir (2012) reported a weak positive correlation between the number of posts and level of cognitive engagement in an undergraduate technology course. Similar to that study, the analysis on RQ3 showed quantity of postings did not equate to knowledge acquisition and results indicated that there was no meaningful relationship between the average forum contributions per unit and the TPACK growth in highly active learners. Furthermore, parametric testing showed there was no correlation between the how active learners were in the forums and the change in TPACK knowledge. Several research studies have had mixed findings addressing levels of participation centered on quantity in discussion forums and cognitive engagement (Kew & Tasir, 2021; Wang, Yang, Wen, Koedinger & Rose, 2015; Wise & Cui, 2018). Quality addressed the relationship between participants TPACK growth and modes of discussion parsed by disposition. For the attribute of quality, the TPACK framework was used in conjunction with the levels of engagement categorized using the productive online discussion model. Several studies have explored the relationship between TPACK and other attributes like self-efficacy, achievement levels, and GPA scores and found that there were positive correlations between these diverse attributes and TPACK (Abbitt, 2011; Erdogan & Sahin, 2010; Tokmak, Ogelen, & Incikabi, 2013). Graham, Borup, and Smith (2012), found that over time the quality of teacher candidates discussions increased. Like the findings of Graham et al., (2012), results from this section show that there was a meaningful relationship between participants TPACK gains and postings that discussed to critique, construct knowledge, and share improved understanding. Eight of ten highly active teacher learners experienced TPACK gains greater than 1.0. These participants forum contributions were more frequently coded as posts that critiqued, constructed knowledge, and shared improved understanding than those with lower TPACK growth.

Limitations

The scope of this research study was limited to the study of the Teaching Mathematics with Technology (*TMT*) MOOC-Ed course at NC State University. The *TMT* MOOC-Ed is uniquely designed with principles that encourage integrated approaches to strengthen teacher learning. Therefore, the findings of this study may be generalized to professional learning courses on teaching mathematics with technology specifically designed for mathematics educators. The research-based designed principles promote self-directed learning, learning from multiple perspectives, peer-supported learning, and job-connected learning.

The first limitation is the sample size of highly active teacher learners. There were ten of the thirty-nine participants categorized as highly active. Exhaustive normality testing was conducted on the thirty-nine active learners and the ten highly active learners. Both sample participants TPACK scores were determined to be normal. However, *p*-values are highly influenced by sample size, and this could have been a contributing factor as to why there was no significant difference in TK, PK, and CK of highly active teacher learners. To counteract this limitation, this study emphasized effect size as the most important measure in determining the effect of participating in the *TMT* MOOC-Ed had on teacher learners TPACK knowledge. Moreover, sample size has no influence on how effect size is calculated so this measure served as a more appropriate indicator for change in teacher knowledge (Coe, 2002; Fritz et al., 2012; Sullivan & Fein, 2012).

The third limitation deals with the scope of this study. Criterion sampling limited the number of participants for this study and analyzing discussion forum postings were exclusive to participants who completed both the pre- and post- TPACK surveys. Intensity sampling selected a subsample of research participants from the criterion sample (Palinkas, Horwitz, Green, Wisdom, Duan, & Hoagwood, 2015). Although study findings showed teacher knowledge increased while the course progressed in both active and highly active teacher learners, it is not apparent how participants newfound knowledge is enacted in their teaching practice. Additionally, the TPACK survey was self-reported data on how participants perceived a change in their knowledge. Extending qualitative methods of data collection and analysis would be helpful in supporting the validity of these findings. However, this research does provide findings and implications for online teacher learning and professional development.

Finally, the fourth limitation are the internal and external factors that influence technology integration in the classroom. Several studies note that teacher beliefs about technology use, students, and learning influence teachers' decision-making regarding the extent of and types of use in the classroom (Ertmer, Paul, Molly, Eva, & Denise, 1999; Hall, Hord, Aguilera, Zepeda, & von Frank 2011; McCulloch, Hollebrands, Lee, Harrison, & Mutlu, 2018). External factors like accessibility to technologies including internet services in remote areas influenced by geographical location, state, district, and school level constraints. In a recent study, McCulloch et al., (2018) noted that teachers had access to multiple types of technologies (e.g., laptops, cell phones, graphing calculators). However, there were not enough of each technology for every student in the class to have the same type of device. Lastly, there may be logistical and pedagogical issues (i.e., logins, internet connections, classroom management facilitating student conversations) that occur at the classroom level that influence how and to what extent technology is integrated to impact student learning outcomes.

Implications for Research

The results of this study generated several implications and recommendations despite the limitations of this study. This research provides implications for other researchers, teacher educators, designers of online learning, pre-service and current teachers. This study was interested in studying the ways teachers learn in professional learning courses. In this section, implications for designers of online learning, teachers of online learning and future research are addressed.

The processes involved in understanding teacher learning are complex with many multi-dimensional relationships. This study adds to the existing field of research focused on mathematics teacher learning in professional learning courses. The findings of this study provided insight on how teachers learned in the *TMT* MOOC-Ed experience through their discussions with colleagues in forums and the relationship between self-reported knowledge acquisition and those interactions with their colleagues.

Implications for Designers of Online Learning

The most significant implication of this study is the impact participation in the *TMT* MOOC-Ed had on participants professional learning. Designers of online learning for teachers should be aware of the diverse learning needs of their target audience. The design principles and research-based practices used in the development of the MOOC-Ed provided a multi-faceted learning experience for mathematics educators. The course design centers on four tenets: (a) self-directed learning, (b) learning from multiple voices, (c) job-connected learning, and (d) peer-supported learning (Kleiman et al., 2014). Participants experienced *self-directed learning* opportunities through asynchronous engagement in the discussion forums. Teacher learners had the flexibility and autonomy to choose when and what levels of engagement were compatible with their personal learning goals (Hollebrands & Lee, 2020). Although participants reported distinct reasons (Figure 3.2) for enrolling in the course, having access to differentiated activities, resources, and content that supported their learning supported their continuous engagement to course completion.

Designers of online learner should also consider the second principle of *multiple voices*. Participants had the opportunity to hear and learn from each other in the forums, learn from instructors, and watch videos of experts in the field of mathematics and mathematics research (Hollebrands & Lee, 2020). This was voiced and echoed by participants in the discussion forums while discussing and sharing information about their own learning in the different units. The third principle of *job-connected learning* deals with providing participants with ready-to-use resources, accessing rich tasks and activities, and viewing videos that are relevant to their teaching practices. Powell and Bodur (2019) found that effective online teacher professional development considers the different contexts for which teachers practice and they are more likely to implement in their classrooms due to practicality. In the discussion forums, participants had opportunities to reflect on their own exploration of tasks, analyze student work with various technology tools, and share their thoughts and ideas with their peers. Several participants elaborated on real-time implementation of tasks and activities they accessed in the MOOC while they were actively participating in the course. The fourth principle and the most important for this study was p*eer-supported learning* in which interaction with other participants are encouraged mostly through discussion forums. In this MOOC-Ed, participants took advantage of the opportunity to interact with their peers. Of the 147 registered participants who accessed the course, 39 (26.5%) were categorized as active participants who posted an original post or reply at least once in each of the four forums. Several studies have noted the importance of forum engagement as a precursor to course completion and knowledge acquisition. Cohen, Shimony, Nachmias, and Soffer (2019) found that learners consistently active in forums completed courses at a higher rate while others have noted that the most active users were influential and had a positive effect on forum health (Huang et al., 2014; Wong et al., 2015). Like the findings on the quality of discussion forum posting in this study, Wang et al., (2015) observed that constructive forum participation was a predictor of student learning gains.

Implications for Teachers of Online Learning

The second implication for this study focuses on teachers of online learning. Over the years, research conducted has consistently recognized key tenets for successful participant engagement and learning in online environments. Authentic tasks and relevant content, questioning that elicits higher order thinking, and opportunities for reflection are essential elements worth consideration when structuring an online learning environment.

Authentic Tasks and Relevant Content. Literature indicates that knowledge acquired in a professional learning course should be useful and inform teaching practices (Dede, et al. 2009; Powell & Bodur, 2019). Professional learning developers and online teacher instructors should consider the highly contextualized learning needs of educators and provide authentic and relevant tasks that relate to their practice (Vrasidas & Zembylas, 2004). Participants in these courses will be more likely to adapt the resources provided to their own teaching practices to positively impact student learning. Participants in the *TMT* MOOC-Ed communicated their appreciation in forum postings and unit surveys about how the resources, tasks, and technology tools were applicable to their classroom practices and suitable to use with their students. On the end-of-course survey, 60% of participants responded ‘yes’ to attempting to make changes in their professional practice while participating in the course. Participants expressed several ways that they had made changes or had incorporated resources and tools into their classrooms or departments while working in the MOOC-Ed. Some had implemented technology-based activities into their lesson plans while one employed the technology evaluation tool to find tasks appropriate for algebra content, while another participant implemented CODAP in the high school mathematics department. Providing authentic tasks and meaningful contextualized content relevant to teachers learning goals has a positive effect on their engagement during professional development and subsequent enactment of their professional learning in the classroom.

Questioning that elicits higher order thinking. Teachers and facilitators of online learning should consider the types of question posed in discussion forums. Questioning that is specific to targeted learning outcomes elicit favorable responses from students. Research has shown that there is a strong relationship between the types of questions crafted by teachers and the learners ensuing responses (Ertmer et al., 2011). Structuring question prompts in a way that requires synthesis of materials, justifying responses, and acting on prior knowledge is influential for higher order thinking in discussion forums (Bradley, Thom, & Hay, 2008). In this study, the diverse types of forum prompts (see Appendix C) afforded participants opportunities to engage with their colleagues in meaningful ways to elicit higher levels of thinking as evidenced from the study findings. The types of forum posts (i.e., analyze student thinking, reflect on own exploration) enhanced the quality of learning in the online forums. However, there were few discussions categorized as discussing to construct knowledge and discussions to share improved understanding. This is related to the focus of the discussions for each unit forum. Additionally, examining the discussion forum contributions using the productive online discussion model as a framework addressed several types of learning including cognitive presence, social construction of knowledge, argumentation, and critical thinking (Gao, et al., 2009). Teachers and online facilitators should be knowledgeable of the research-based practices of questioning as a primary strategy to facilitate participant interactions, increase participant engagement, enhance the quality of forum postings, and improve participant learning.

Opportunities for Reflection. Literature supports the need for reflection as an important aspect of online teacher learning (Huang, 2002; Scott & Scott, 2010). Teachers of online learning should consider providing ways for which educators and students reflect on their interactions with course content, their colleagues, and their personal experiences. Reflection on decision-making and practice has become increasingly important in teacher education programs and teaching practice (Sööt & Viskus, 2015). Although this study did not speak specifically to the importance of reflection, there were explicit and implicit opportunities for reflection in discussion forums. Some forum prompts specifically addressed reflection stating, 'Reflect on your own exploration and share your perspective' while other reflective moments like 'Based on your analysis of student work and your own work share your thoughts' were more implicit in nature. Reflection was an intrinsic attribute that was necessary to adequately respond to forum prompts and promote discussion with colleagues. When participants reflect there is an increase in depth of knowledge including contextualized knowledge and reflective activities promote learning in online environments (Chang, 2019). This was evidenced in the findings of this study as participants patterns of discussions and learner actions shifted as the course progressed. Initially, participants discussed to comprehend much more than other modes of discussion. As the MOOC progressed, discussions that critiqued, constructed knowledge, and shared improved understanding increased over the duration of the MOOC.

Implications for Future Research

The scope of this study involved mathematics teachers enrolled for five weeks in an online professional learning course. Demographic enrollment data was collected, unit discussion forums were analyzed using qualitative methods, and quantitative statistical testing was conducted on self-reported TPACK surveys. Given the potential constraints of using self-reported data with inconsistent ratings and potential bias, this author recommends additional methods of data collection and analysis (e.g., follow-up interviews, focus groups, classroom observations, artifacts of practice) to better ascertain what teachers learned in their MOOC-Ed experience and how this knowledge is being enacted in the classrooms. Several studies have used TPACK as a framework to examine mathematics' teachers integration of technology in the classroom through observations of teacher instructional practices (Patahuddin, Lowrie, & Dalgarno, 2016; Urbina & Polly, 2017) Ultimately, the quintessential goal of professional teacher development research is to bridge empirical evidence of teacher learning to student learning outcomes (Polly, McGee, & Martin, 2010). Mathematics education researchers should consider ways in which TPACK is used to present rich representations of technology implementation in teaching practice and the significance of TPACK on student achievement.

A second recommendation for future research would be to consider how the duration of a professional learning course affects participation and attrition rates. Although this study did not focus on duration, the *TMT* MOOC-Ed is a five-week long course that is designed for participants to complete one unit per week. Of the 147 enrolled participants, forty-seven participants received certificates of completion (31.9%) with thirty-nine of those forty-seven (83.0%) agreeing to participate in this study. This high rate of completion contradicts the typical trends that occur in online learning and may be explained by a combination of several factors including course design, short, sustained duration, relevant content, and active learning opportunities. From 2016 onwards, high attrition and dropout rates have been studied extensively (Badali, Hatami, Banihashem, Rahimi, Norozzi, & Eslami, 2022; Dalipi, Imran, & Kastrati, 2018; Zhy, Sari, & Lee, 2020). Desimone's (2009) salient article puts forth the five features of professional development and highlights sufficient duration as a critical element of studying teachers' professional learning. Although research has not determined a critical point where lasting change occurs in teacher knowledge and pedagogical practices, Desimone recommends twenty hours or more of contact time for changes to occur in teacher learning and practice. Subsequently, the *TMT* MOOC-Ed certificates of completion are issued after twenty hours of course participation. Future research could employ measures to determine how the duration of professional learning courses affect engagement and completion rates.

A third suggestion for future research is to employ language technologies (i.e., text mining tools) to analyze discussion forum posts to explore online interactions. Sentiment analysis often referenced to as ‘text mining’ or ‘emotional AI’ is defined as “natural language processing for tracking the mood of the public about a particular product or topic” (Vinodhini & Chandrasekaran, 2012). Mentioned in the second recommendation, massive open online courses can have extremely high dropout rates up to 90% in the first few weeks of the course (Ang, Ge, & Seng, 2019; Reich & Reiperez-Valiente, 2019). This may be due to complex emotions such as frustration, premature evaluations of course content, boredom, or excitement (Eriksson et al., 2017). Sentiment analysis of participants forum contributions may help curtail the typically high attrition rates in MOOCs. Another possible affordance of employing sentiment analysis on discussion forums is to gain insight into how participants are reacting to course materials and activities to perform real-time modifications on the learning environment to increase learner engagement and user satisfaction (Moreno-Marcos, Alario-Hoyos, Muñoz-Merino, Estévez-Ayres, & Kloos, 2018). Finally, collective sentiment analysis could support teachers and instructors understanding of participants insecurities with course components for revisions and modifications to accommodate participants professional learning needs.

Conclusion

In the last twenty years, the necessity for teachers and educators to integrate technologies into their teaching practice has forced many educators to retire from teaching earlier than expected or left some isolated from colleagues within their respective departments. This phenomenon is more apparent when teachers have limited access to professional development opportunities due to constraints (i.e., limited district expenditures) beyond their control. It has been well documented that teachers acknowledge the importance and value of effective professional development and the significant impact it has on teacher effectiveness. With such emphasis on technology use and support for teachers to use technology, teachers should have equitable access to high quality professional development. Professional learning courses like MOOC-Eds provide a convenient and flexible learning option where teachers can receive peer support from their colleagues, access high-quality content, and implement research-based practices in their respective fields.

Teaching and learning in distance and online spaces is occurring at an exponential rate. As a result, mathematics teachers are compelled to become technologically competent in new ways of teaching and learning. As the need for informal professional development increases, it is advantageous for the research community to continue exploring the impact of active participation in these courses. In this study, findings showed that participation in the *TMT* MOOC-Ed led to TPACK knowledge acquisition and reported implementation of learning content in participants mathematics classrooms.

Subsequently, as professional learning courses become more common in education, it is advantageous for the research community to continue exploring the effect that engagement can have on teachers learning experiences.

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APPENDICES

Appendix A

Informed Consent for Secondary Data for Research (*TMT* MOOC-Ed, Friday Institute, n.d.)

Title of Study: Characterization of Highly Active Teacher Learners' Participation and TPACK Knowledge While Engaging in a Teaching Mathematics with Technology MOOC for Mathematics Educators

eIRB # 25694
Principal Investigator(s): James Smiling, jfsmilin@ncsu.edu (910) 474-6595
Funding Source: None
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You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate, and to stop participating at any time without penalty. The purpose of this research study is to gain a better understanding of the Teaching Mathematics with Technology professional learning experience for which you are registered. The study will collect data through your professional learning in the form of all course surveys (enrollment survey, unit feedback surveys, and the pre-and post-TPACK surveys). discussion forum posts, and demographic information you provide.

Participating in the research is voluntary, and you can stop your participation at any time. In order to stop your participation, please contact Mr. James Smiling (jfsmilin@ncsu.edu and 910-474-6595). If you choose to withdraw your consent and to stop participating in this research, you can expect that the researcher(s) will redact your data from the data set, securely destroy your data, and prevent future uses of your data for research purposes wherever possible. You must be 18 years of age or older, reside in the United States to participate in this study. There are minimal risks associated with your participation in this survey. You will not receive compensation for completing this survey.

If you have any questions about the survey, how it is implemented, or the research study, please contact Mr. James Smiling (james.smiling@ncsu.edu and 910-474-6595) or Dr. Karen Hollebrands (kfholleb@ncsu.edu and 919-513-0505). You can also contact the faculty advisor for this research, Dr. Karen Hollebrands, at kfholleb@ncsu.edu, and (919) 513-0505. Please reference study number 25694 when contacting anyone about this project.

If you have questions about your rights as a participant or are concerned with your treatment throughout the research process, please contact the NC State University IRB Director at IRB-Director@ncsu.edu, 919-515-8754, or fill out a confidential form online at https://research.ncsu.edu/administration/compliance/research-compliance/irb/irb-forms-and-templates/participant-concern-and-complaint-form/

If you consent to complete this survey, please select the "Yes, I consent to participating in this research study button."

Appendix B

Technological Pedagogical Content Knowledge (TPACK) Survey
(1) Strongly agree (2) Agree; (3) Neither agree nor disagree; (4) Disagree; (5) Strongly disagree.

1. I know how to solve my own technical problems.
2. I can learn technology easily.
3. I keep up with important new technologies.
4. I frequently play around with the technology.
5. I know about a lot of different technologies.
6. I have the technical skills I need to use technology.
7. I have sufficient knowledge about mathematics
8. I have various strategies for developing my understanding of mathematics.
9. I know about various examples of how mathematics applies in the real world.
10. I have a deep and wide understanding of algebra.
11. I have a deep and wide understanding of geometry.
12. I know how to assess student performance in a classroom.
13. I can adapt my teaching based upon what students currently understand or do not understand.
14. I can adapt my teaching style to different learners.
15. I can assess student learning in multiple ways.
16. I can use a wide range of teaching approaches in a classroom setting.
17. I can use strategies that combine mathematics, technologies, and teaching approaches that I learned about in my coursework in my classroom.
18. I can choose technologies that enhance the mathematics for a lesson.
19. I can select technologies to use in my classroom that enhance what I teach, how I teach, and what students learn.
20. I can teach lessons that appropriately combine mathematics, technologies, and teaching approaches.
21. I can teach lessons that appropriately combine algebra, technologies, and teaching approaches.
22. I can teach lessons that appropriately combine geometry, technologies, and teaching approaches.

Appendix C

Teaching Mathematics with Technology MOOC-Ed Discussion Forum Summary

	Type of Forum Post	Content	Multimedia	Focus of Forum
Unit 1				
EE 1	Analyze student thinking	Algebra	Video	Student use of technology
CP 1	Analyze student thinking	Algebra	Video	Compare students' work to own work
Unit 2				
EE 2a	Sharing ideas & resources	Algebra	None	
EE 2b	Analyzing task	Algebra	Video	How technology is used
CP 2a	Analyzing task	Geometry	None	Analyzing geometry tasks
CP 2b	Analyzing task	Statistics	None	Analyzing statistics tasks
Unit 3				
EE 3a	Analyze student thinking	Geometry	Video	Student use of technology
EE 3b	Reflect on own exploration	Geometry	None	Reflect on exploration of geometry task
EE 3c	Sharing ideas & resources	Geometry	None	
CP 3a	Reflect on own exploration	Function	Student	Student thinking & analyzing tasks
CP 3b	Reflect on own exploration	Geometry	Video	Student thinking & analyzing tasks
CP 3c	Reflect on own exploration	Statistics	Video	Student thinking & analyzing tasks
Unit 4				
EE 4a	Analyzing orchestrating discussions	Statistics	Animation	Share your analysis and respond to colleague analysis
EE 4b	Reflect on own exploration	Statistics	None	Share and respond to colleague reflection
EE 4c	Share ideas & resources	Statistics	None	
CP 4a	Analyzing orchestrating discussions	Algebra	Animation	Analyzing teaching

Appendix C (continued)

Teaching Mathematics with Technology MOOC-Ed Discussion Forum Summary

	Type of Forum Post	Content	Multimedia	Focus of Forum
CP 4b	Analyze orchestrating discussions	Geometry	Animation	Analyzing teaching

Appendix D

Teaching Mathematics with Technology MOOC-Ed Discussion Forum Prompts

Unit	Type of Forum Post	Forum Prompt
U1 EE	Analyzing Student Thinking/ Work	How were conveyance and mathematical action technologies used by the students in the video to support their work on the task?
U1 CP	Analyzing Student Thinking/ Work	Describe how the work of students without technology compares to the students who used technology and your own work on the task.
U2 EE	Sharing Other Ideas/Resources	Share other thoughts and ideas with your colleagues.
	Analyzing Task	Discuss how technology was used as an amplifier and as a reorganizer.
U2 CP	Analyzing Task	Based on your analysis of the Properties of the Mean and the Median task, describe what you liked about the task and why. Also explain what changes you would make.
	Analyzing Task	Based on your analysis of the Pick's Theorem task, describe what you liked about the task and why. Also explain what changes you would make.
U3 EE	Analyzing Student Thinking/ Work	Share your or respond to a colleague's analysis of students' work on the Mystery Transformations Task.
	Sharing Other Ideas/Resources	Share other thoughts and ideas with your colleagues.
	Reflecting on Own Exploration	Reflect on your own exploration of the Mystery Transformation Task.
U3 CP	Reflecting on Own Exploration	Did the task involve direct manipulation? How? Was direct manipulation an essential component, and did it support students' mathematical thinking? How would you describe the cognitive demand of the task? Was the Task Analysis Guide helpful in focusing your critique?
	Reflecting on Own Exploration	Did the task involve direct manipulation? How? Was direct manipulation an essential component, and did it support students' mathematical thinking? How would you describe the cognitive demand of the task? Was the Task Analysis Guide helpful in focusing your critique?

Appendix D (continued)

	Reflecting on Own Exploration	Did the task involve direct manipulation? How? Was direct manipulation an essential component, and did it support students' mathematical thinking? How would you describe the cognitive demand of the task? Was the Task Analysis Guide helpful in focusing your critique?
U4 EE	Sharing Other Ideas/Resources	Share other ideas and resources with your colleagues by replying to this post.
	Analyzing Orchestrating Discussion (Five Practices)	Share your or respond to a colleague's analysis.
	Reflecting on Own Exploration	Share your or respond to a colleague's reflection.
U4 CP	Analyzing Orchestrating Discussion (Five Practices)	What did you notice about the way the teacher discussed the different solutions to the tasks? How would you describe the way in which she sequenced students' work? What suggestions do you have for the teacher in the animation for leading the class discussion?
	Analyzing Orchestrating Discussion (Five Practices)	What did you notice about the way the teacher discussed the different solutions to the tasks? How would you describe the way in which she sequenced students' work? What suggestions do you have for the teacher in the animation for leading the class discussion?

Appendix E

Teaching Mathematics with Technology MOOC-Ed Technology Tools and Support

Technology Tools and Support

The following tools are some of our favorite for engaging in technology-enabled mathematics tasks. The descriptions include information on where the tool can be accessed. Throughout the course, we will ask that you explore how to use these tools to support students in developing conceptual understanding around important mathematical ideas. We encourage you to explore what these tools have to offer.

Desmos

This free HTML5 Desmos graphing calculator is used by students and teachers all around the world. Desmos is web-based and runs seamlessly on iPhones, iPads, Android phones, and Windows touch devices. In addition, Desmos creates classroom activities on *top* of that calculator to help students and teachers use this powerful tool to experience all the curiosity, beauty, and sense that math has to offer. To assist teachers, Desmos created an Activity Builder, a DIY tool for helping educators create Desmos-based activities to use with students. As Desmos makes their tool more powerful, faster, and easier to use, they share these free upgrades.

Rate this resource:- Bookmark this Resource Share |

GeoGebra

GeoGebra, a free web-based tool, is dynamic mathematics software designed for students and teachers across various grade levels. It can also be downloaded on a computer or mobile devices, such as tablets and phones. This tool brings together geometry, algebra, spreadsheets, graphing, statistics and calculus in one easy-to-use platform. GeoGebra, a leading provider of dynamic mathematics software, is a rapidly expanding community of millions of users from all around the world. A list of Featured Materials includes activities and interactive technology files.

Rate this resource:- Bookmark this Resource Share |

Google Sheets

Author: Google

Google provides a free spreadsheet that can be used individually or editted live by a group of users. It be used as a stand-alone app, or integrated and used within Google Classroom. It integrates well with Excel so you can open Excel files within Google Sheets, or save Sheets files in Excel format. You can also save files as .csv or .txt, which is helpful for saving data to import into other data programs.

Rate this resource:- Bookmark this Resource Share |

CODAP

Source: The Concord Consortium

This is a free, web-based tool that allows you and your students to explore, play, and learn from data using their dynamic links between multiple representations across tables, graphs, and maps. You can drop in data for exploration and embed a simulation or game that generates data and explore data with ease. This website also includes multiple data sets, activities, and graphical displays for you and your students to play with. If this is your first time using the CODAP tool, you may want to explore the *Getting Started With CODAP* interactive guide. This guide is a short tutorial that will familiarize you with some of the basic features of CODAP. You can also learn more about how use CODAP on the CODAP Help page.

Rate this resource:- Bookmark this Resource Share |

Tuva

Source: Tuva

This is an online data tool and data activity repository inspired by TinkerPlots. Tuva is designed to make open data useful for teaching and learning data literacy across the curriculum by offering teachers and students a platform to analyze, visualize, and interpret real data around issues related to their communities and interests. While you are at the site, you may want to check out their data sets, 25 of which are free, as well as teacher-written activities.

Rate this resource:- Bookmark this Resource Share |

Appendix F

Enrollment Survey Questions

1. What was your primary reason for enrolling in a MOOC-Ed course?

    a. Deepen my knowledge of the course topic(s)
    b. Collect resources and tools for my practice
    c. Earn a certificate of accomplishment/renewal credits
    d. Just browsing
    e. Connect with peers/colleagues
    f. Other

2. How confident are you in teaching mathematics with technology? 5-Point Likert Confidence Scale.

    - Completely confident
    - Very confident
    - Moderately confident
    - Somewhat confident
    - Not at all confident

3. How often do you use technology to teach mathematics?

    - Never
    - A few times each year
    - A couple of times each grading period
    - A few times each month
    - A few times each week
    - Everyday

4. Why did you enroll in the *Teaching Mathematics with Technology* MOOC-Ed?

Appendix G

Coding Rationale and Sample Excerpts

<u>Disposition One-Discuss to Comprehend</u>

Learner action a: Interpreting or elaborating the ideas by making connections to the learning materials.

Coding rationale: Participant made direct connection to the video and technology tool in the unit.

“Desmos was used as a mathematical action technology to try different equations of fit to the data, and the app was used to fit the pennies inside the circle. The results of the students’ predictions were conveyed on the summary page for other students to observe.”

Learner action b: Interpreting or elaborating the ideas by making connection to personal experiences.

Coding rationale: Participant made connection between the task and her personal experience with her students.

“I tried to explain this with examples to students in the past, but this activity is so much better than what I've done before.”

Learner action c: Interpreting or elaborating the ideas by making connections to other ideas, sources, or references.

Coding rationale: Participant made connection to the MOOC content using references to outside sources.

“Here is a Google Sheets spreadsheet that takes an error analysis approach to the Penny Circle Task
https://docs.google.com/spreadsheets/d/1UVb6n2p9WwNrMn7LwL58a9aLQO88scXL3yYP75FAVQQ/edit?usp=sharing”

Appendix G (continued)

<u>Disposition Two-Discuss to Critique</u>

Learner action a: Building or adding new insights or ideas to others' posts.

Coding rationale: Participant is agreeing with a previous participant post and adding own experiential insight.

"I agree that a coordinate plane would make it easier to understand, and adding some shapes would also be helpful. But overall, a good visual activity."

Learner action b: Challenging the ideas in the text/MOOC content.

Coding rationale: Participant reflected, critiqued, and challenged the procedures of the task.

"I feel like there wasn't quite enough direction and I would have to do more to help students enter this task. It was just a bit too conceptual."

Overlapping Codes

<u>Disposition One-Discuss to Comprehend and Disposition Three-Discuss to Construct Knowledge</u>

Learner action 1a: Interpreting or elaborating the ideas by making connections to the learning materials.

Learner action 3b: Facilitating thinking and discussions by raising questions.

Coding Rationale: Participant made connection to MOOC content and facilitated discussion by raising a question.

"I do see the advantage of not having a coordinate plane or shape, but wonder doesn't that increase the time students take before they fully understand and engage in the task? I know it took me a bit of time."

Appendix G (continued)

<u>Disposition One-Discuss to Comprehend and Disposition Two-Discuss to Critique</u>

Learner action 1a: Interpreting or elaborating the ideas by making connections to the learning materials.

Learner action 2c: Challenging the ideas in others' posts.

Coding rationale: Participant made connection to MOOC content and challenged the ideas of another post.

"I think this activity provided opportunities for students to engage in productive struggle. There will always be some students that find a task like this as onerous but that is not a reason not to assign the task because many more will benefit greatly doing this task."

<u>Disposition Two-Discuss to Critique and Disposition Four-Discuss to Share Improved Understanding</u>

Learner action 2a: Building or adding new insights or ideas to others' posts.

Learner action 4b: Synthesizing discussion content.

Coding rationale: Participant replied to several other threaded discussion postings critiquing the technology tool. The participant added new insight after synthesizing the discussion content.

"I'm sorry to hear that. There is time needed to be able to use all the features of the application, but I do think it is user-friendly. I really like the application and its use in the classroom to move our students from calculators to problems solvers."

Discussions Coded as 'Other'

Coding rationale: Forum contributions could not be coded as discussing to comprehend, critique, construct knowledge, or share improved understanding.

"I agree!," "I couldn't have said it better," "Thank you for the information.," "I loved this activity."
