# Exploring the role that teacher characteristics and multi-dimensional beliefs play in technology integration uptake for teaching and learning in secondary mathematics classroom: A mixed methods approach

by

Marybeth Lao Bano-Rizzo

B.S., Philippine Normal University, 1998
M.Ed., Southwestern College, 2019

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree.

DOCTOR OF EDUCATION

Curriculum and Instruction
College of Education

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2024

## Abstract

This study explored the role of secondary Mathematics teachers' characteristics and multi-dimensional beliefs in integrating technology into teaching practice (i.e., mode of technology use).

The research design employed is the convergent mixed method. The quantitative strand employed an electronic survey with 83 respondents. It has one primary question and four sub-questions, all about the relationship between the mode of technology use and each of the four predictor variables-teacher characteristics (gender, age, experience, education, grade level taught); beliefs about teaching with technology, self-efficacy beliefs, and epistemological beliefs all of which are measured in multi-level Likert scale. The qualitative strand employed a case study approach with four teacher participants. The data collection included an initial interview, a semi-structured follow-up interview, and classroom observation.

The significant findings include that discovering learning (constructivist practices) is the primary mode of technology use. The driving force behind this phenomenon is multidimensional, including teacher self-efficacy beliefs, beliefs about teaching with technology, and teacher pedagogical beliefs. Teacher age, experience, and educational level also play a role, but teacher characteristics, in general, do not play a pivotal role in the use of technology in the mathematics classroom.

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Approved by:

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## Dedication

This dissertation is dedicated to my family-

Most especially to my husband, Mark- for the love and support during my doctoral journey.

# Chapter 1 - Introductory Chapter

The Organization for Economic Development (OECD) Future of Education and Skills 2030 project identified two phases of curriculum change to meet the requirements of the future (knowledge-based) economy. The first phase (2015-19) focuses on "what" competencies (knowledge, skills, attitudes, and values) students need to be successful in terms of both individual and societal well-being. The second phase (2019 and beyond) focuses on "how" to design learning environments that can nurture such competencies (i.e., how to implement curricula effectively). The report talked about how education systems have (or have not) evolved in response to societal demands. Education experts noted that the 21st-century students living in a 21st century, "the age of accelerated technological innovation, social media, Artificial Intelligence, robotics, the Internet of Things and 3-D printing, among many others" (Gal et al., 2019) are still being taught by teachers using 20th-century pedagogical practices (Schleicher, 2018).

The COVID-19 pandemic highlighted the digital divide across the world. The United Nations International Telecommunication Union (ITU) revealed an estimated 0.8 billion increase in the global growth of internet use between 2019 (4.1 billion) and 2021(4.9 billion). On the other hand, 2.9 billion people (around thirty-seven percent) have no internet access, 96% of whom live in developing countries. In the United States alone, access to a smart device and the internet seemed universal but not uniform. For example, rural areas tend to have slower, non-WIFI mobile technologies, and counties with higher minority and older populations tend to use slower mobile technologies (McFarland et al., 2019). In addition, the NCES report in 2019 showed that lower-income families tend to access the internet using a smartphone and are therefore limited in terms of functionality, such as word processing or access to interactive

learning platforms (masking the digital divide/inequities), impacting the ability as an educational tool. To close the homework gap, the FCC spent $7.17 billion for the emergency connectivity fund to help provide laptops, tablets, Wi-Fi hotspots, modems, routers, and broadband connectivity for out-of-campus use for students, teachers, and staff as part of the American Rescue Pal Act of 2021 (FCC, 2022).

In 2018, Dell Technologies predicted that 85 percent of jobs in 2030 still need to be created. With this, schools must prepare learners for lifelong learning and evolving careers. But "how can schools build a student for the 21st Century that can think their way through abstract problems, work in teams, distinguish good information from bad, or speak a language other than [their own]?" (USDOE OET, 2017). The 2017 National Education Plan Update included the need for people to learn 21st Century competencies, develop a sense of agency in their learning and the belief that they are capable of succeeding in school: non-cognitive competencies (i.e., forming relationships and solving everyday problems, self-awareness, control of impulsivity, executive function, working cooperatively, and caring about oneself and others) (p. 10). It also talks about technology-enabled learning in action, the future of learning technologies, bringing equity to learning through technology, providing technology accessibility for all learners and physical spaces, and technology-enabled learning. It recommended more research on how the learning sciences-the scientific study of how people learn inform how technology is developed and used in school settings (USDE OET, 2017, p. 25)

The International Society for Technology in Education (ISTE) Standards for students include preparing students to thrive in an ever-changing technological world by empowering learners to be digital citizens, knowledge constructors, innovative designers, computational thinkers, creative communicators, and global collaborators (ISTE, 2022). In concurrence with

the above, the National Council of Teachers of Mathematics (NCTM, 2014) posits that teachers and students must regularly access technologies that support and advance mathematical sense-making, reasoning, problem-solving, and communication. Teachers are encouraged to use technology strategically to provide access to mathematics for all students.

## Statement of the Problem

However, the research on technology use or integration for the secondary mathematics classroom has mixed results, if not wanting. It was found that teaching mathematics with technology is quite a challenge (Viberg et al., 2020). It is difficult to pinpoint why this is so; some research suggests it is multi-dimensional. It is not one or two factors but a bunch of them, including teachers' characteristics and knowledge of mathematics; held views, attitudes, and beliefs about mathematics teaching and mathematics learning (Ernest, 1989); self-efficacy beliefs (Thurm & Barzel, 2021), and beliefs about teaching with technology (Thurm & Barzel, 2021) among others.

In this study, I explored the characteristics of in-service secondary Mathematics teachers, their multidimensional beliefs (beliefs about mathematics as a discipline, mathematics teaching and learning, self-efficacy beliefs, and beliefs about teaching with technology), and their mode of technology use.

## Research Questions

***Quantitative Strand***. This strand will focus on in-service secondary mathematics teachers.

in the United States. By taking a substantially large quantity of teachers, common features shared by that group can be identified. The primary research question for this study includes, "What teachers' characteristics and multidimensional beliefs are associated with the mode of

technology used in teaching math in the secondary classroom?" The secondary questions appear as follows:

SubQ1: To what extent, strength, and direction are teacher characteristics (gender, education level, experience, professional development) associated with the mode of technology use?

SubQ2: To what extent, strength, and direction are teachers' beliefs about teaching with technology associated with the mode of technology use?

SubQ3: To what extent, strength, and direction are teachers' epistemological beliefs associated with their mode of technology use?

SubQ4: To what extent, strength, and direction are teachers' self-efficacy beliefs associated with their mode of technology use?

***Qualitative Strand*.** The primary research question of the qualitative strand is, "Do teachers' multidimensional beliefs translate classroom practice in terms of technology use (i.e., mode of technology use) in teaching mathematics?"

SQ5: How does teachers' belief translate into classroom practice (i.e., mode of technology use) in teaching and learning Math?

SQ6: What are the barriers to incorporating technology in teaching and learning Math?

***Mixed Methods***. The mixed methods question is: How do the survey and case study findings align? Specifically, the role of secondary mathematics teachers' characteristics and multidimensional beliefs in teaching practice (i.e., mode of technology use).

To answer these questions, I employed a mixed-methods convergent parallel research design with two simultaneous strands- the quantitative and the qualitative strand. The quantitative strand will include a Likert-scale type quantitative survey of a large sample while

simultaneously a qualitative strand single case study with four (4) purposefully selected individuals to explore those results in more depth, for which data sources include an initial interview, semi-structured follow-up interview and field notes from class observation. The qualitative data and the quantitative result will be analyzed individually and jointly, giving context, and providing a holistic and synergistic view of the study.

## Purpose and Significance of the Study

The debate on technology used to assist instruction has been ongoing for 60 years. Research shows that teaching with technology improves the learning of Mathematics (Borji et al., 2019). In addition, mathematics instruction with technology benefited conceptual and procedural learning (Thurm & Barzel, 2021). However, researchers have found that some mathematics teachers are apprehensive about integrating technology into their instruction (Lavicza, 2010). In addition, it has been noted that existing studies about beliefs and technology integration have been predominantly single-item measures or too course-grained (Thurm, 2021), offering limited insight into teacher beliefs' multi-dimensionality. In this view, this study will add to the existing knowledge in mathematics education about teacher belief and technology use.

## Limitations and Delimitations of the Study

The limitations of this design are the amount of time and the feasibility of resources to collect results from both types of data. A nonresponse bias is anticipated due to the method of data collection- a teacher survey for the quantitative strand. It is also a limitation that a voluntary sample is not randomly selected; thus, it may not represent the population. This limits the generalizability of the results of our quantitative study strand. However, the sample is large enough, so there is a good chance we will capture the truth with some uncertainty.

As for the qualitative strand, a single case study, bias is anticipated due to the purposeful sampling method since those who volunteer to be case study participants may be systematically different from those who did not participate; results will likely favor similar types of teachers as those who volunteer. Nevertheless, the qualitative strand helps explain my findings in a deeper and more nuanced way because I did not only interview the participants but also observed them in action. This process allowed for data triangulation, which may provide some confirmation of the alignment of self-reported modes of technology use and self-reported multidimensional beliefs.

Many factors, including teacher knowledge, curriculum, student context, and teacher efficacy, influence teacher behavior. In this study, however, I only investigated the following: teacher characteristics (gender, age, race, educational level, grade level taught, teaching experience) and multi-dimensional beliefs (beliefs about teaching with technology, self-efficacy beliefs, and epistemological beliefs) that prior literature has identified as indicators of teacher behavior (i.e., modes of technology use). In addition, for data manageability, the quantitative survey instrument used only multiple-choice items for the belief items.

## Definition of Terms

The word ***technology*** in this study refers to any or all digital mathematical technologies for example, but not limited to function plotters, computer algebra systems (CAS), scientific calculators, graphing calculators, simulation tools, dynamical geometry software, dynamical statistical software that allows calculation, multiple representations of concepts, and other similar tools.

***Beliefs***- refer to "psychologically held understandings, premises, or propositions about the world that are thought to be true" (Philipp, 2007)

***Self-efficacy Beliefs*** (or *confidence*) refer to "beliefs in one's capabilities to organize and execute courses of action required to produce given attainments." (Bandura, 1997, p. 382)

***Epistemological (epistemic) Beliefs*** refer to teachers' beliefs about the nature and role of mathematics and the best way to learn mathematics.

***Mode of Technology use (MOTU)***- how technology is used in Mathematics teaching and learning. In this study, MOTU is characterized by five modes: discovery learning (M1), multiple representations (M2), practice (M3), individual learning (M4), and reflection (M5)

**Summary**

Chapter 1 introduces education issues, including a brief historical background and the need to incorporate technology in the mathematics classroom so students can acquire digital competencies. This sets the background for the conception of the investigation for how certain factors, teachers' characteristics, and multi-dimensional beliefs as predictors for teachers to incorporate technology (refer to Figure 1.1 for visual representation) in ways that allow students to potentially construct or co-construct (mathematical) knowledge and gain skills to compete for jobs and opportunities in a globalized and technology-based economy.

**Figure 1.1.**

*Theoretical Framework*

## Chapter 2 - Literature Review

This chapter discussed literature that serves as a theoretical and conceptual basis for this research on secondary mathematics teachers' modes of technology use, multi-dimensional and sub-dimensional beliefs: a) beliefs about teaching with technology, b) self-efficacy beliefs, c) epistemological beliefs, and teacher qualification and characteristics. The discussion will begin with a brief historical background on technology and mathematics. This will be followed by a discussion of beliefs, focusing on teachers' beliefs about teaching with technology, self-efficacy beliefs, and epistemic beliefs. The discussion will also discuss self-efficacy theory (SET), constructivism, and mathematics education.

### Technology and Math: A Brief Historical Background

Technological advancement challenges mathematics education, impacting personal, social, and work life. It has also radically changed the way mathematics is done and used today. This may be due to the ubiquitousness of digital technologies that do all sorts of things, including spitting out accurate mathematical facts in split seconds. Mathematics has been instrumental to many scientific discoveries as a language of science and technology, its applicability to business (i.e., statistics), and many more. All this challenges math educators regarding preparing their students for a world reliant on technology today and in the future. Many factors may explain why it is a challenge (which will be addressed partly in this study), but the recency and the speed at which innovation changes are overwhelming. Here is a brief historical background on digital technology.

While digital technology has generally existed for about 100 years, digital mathematical technologies (DMT) have only existed for about 50 years. There were two eras in digital mathematical technologies: the personal computer era in the 1970s and the connected

technologies era in the 1990s. The use of DMT during the first era focused on a computer acting as a tutor, drill, and practice, among other things. Recent developments have pointed to using DMT as a teaching and learning tool. The recent shift from technology for drill-and-practice to a learning and exploration tool is ushered in by the introduction of GeoGebra and Desmos in math classrooms. The affordance of these tools brought about major pedagogical shifts in teaching and learning practices in the classroom, especially in mathematics.

In the context of secondary mathematics classrooms, digital technologies can be classified as general (non-mathematical) technologies (i.e., word processing, presentation soft wares) and mathematical technologies that allow students to produce mathematical responses based on user input, allowing the student to explore mathematical ideas and observe, make, and test conjectures about mathematical relationships (Dick & Hollebrands, 2011). This enables teachers and students to investigate mathematical objects and connections using different representations and solve mathematical problems (Bos, 1998) differently.

In this study, the term technology refers to these digital mathematical technologies unless otherwise stated. These digital mathematical technologies could include graphing calculators, function plotters, spreadsheets, statistics and geometry packages, computer algebra systems (CAS), Dynamic Geometry Software (DGS), simulation software, and other virtual manipulatives. There are many ways the technology was found helpful in the classroom. Based on the literature, Thurm and Barzel (2021) chose five benefits (i.e., modes of technology use). These are the use of technology for discovery learning, technology for multiple representations, technology for practice, technology for individual learning, and technology for reflection.

## Belief

Belief is a widely studied construct among researchers who want to understand mathematics teaching and learning (Phillip, 2007). A quick Google Scholar search based on the terms teacher and belief located 1,730,000, which is 1,378,000 (1.25%) more than the number of documents in the 1990s. When the term mathematics was added to the search, a total of 489,000 results were located, which is at least twice more than in the 1990s (219,000); a total of 252,000 results when secondary and/or middle or high school was added compared to 33,000 (1.5%) more documents compared to the despite the popularity of research, Phillip (2007) noted that belief was not clearly defined until recently.

***So, what are beliefs***?

In this study and the context of mathematics education, I will use Phillip's (2007) definition of belief as "psychologically held understandings, premises, or propositions about the world that are thought to be true and are different from attitudes and emotions." Ernest (1988) and Grant (1998) maintained that belief can serve as a "filter that influences one's view of some aspect of the world or as dispositions toward action," to which Pajares (1992) suggested that belief is influential to perception; It can shape individuals' interpretation of events. All of these means that people's beliefs could influence their behavior (Bandura, 1977).

Beliefs are never held in isolation (Thompson, 1992). Belief systems are thought to be either static entities to be uncovered or dynamic mental structures susceptible to change considering experiences. Belief systems, a metaphor for describing how one's beliefs are organized in a cluster around a particular idea or object, include three aspects: primary or central, derivative, or peripheral. Albion and Ertmer (2002) mentioned that central beliefs are the hardest to change because they are deep-seated and are related to our identities and self-worth. Derivative

beliefs are more likely to change if they come from the authorities. Peripheral beliefs are the easiest to change because they are more superficial and less critical.

### *Teacher Belief.*

Teacher belief is essential for interpreting experiences, framing problems encountered, and guiding action (Fives & Gill, 2015). Teacher belief also influences teaching practice (i.e., technology use) in the mathematics classroom. Much research suggests that teachers are the most influential factors in student learning and achievement (Mujis & Reynolds, 2015). However, Ertmer et al. (2010) found that teachers' beliefs are "the largest barrier to student-centered technology integration."

### Teachers' Beliefs about Teaching with Technology.

The extant literature about teaching with technology has mixed results. Vongkulluksn, Xie, and Bowman (2018) pointed out that access to technology does not guarantee a change in teaching practice. Dexter, Anderson, and Becker (1999) found no evidence that technology, on its own, is a catalyst of change for teaching practice. Instead, as Zhao, Pugh, Sheldon, & Bryers (2002) claimed, the teacher's belief in the value of technology as a pedagogical tool for their goals makes them more likely to use it. Pajares (1992), in agreement, asserted that beliefs are far more influential than knowledge in determining how individuals organize and define tasks and problems and are stronger predictors of behavior. Ertmer (1999) contented that beliefs are formed through personal experience, first as students and later as teachers, and likely reinforced by the social norms of their colleagues and students' expectations in their classrooms. Meanwhile, Albion & Ertmer (2002) and Cheng, Chen & Chang (2020) found evidence to support the idea that beliefs constructed from direct observation and deduction from another

belief, or an external informational source are fundamental for using and appropriating technology in education.

Many factors can explain technology use. Russell, Bebell, O'Dwyer, & O'Connor (2003) found that the strongest predictor for technology use is the teacher's belief that technology benefits teaching and learning, such as beliefs in the usefulness and ease of using technology (Scherer et al., 2019). Context beliefs about factors that would enable them to be effective teachers and the likelihood of those factors occurring in their schools (Lumpe & Chambers, 2001)- emphasizing the importance of the school environment as an influence on how teachers' beliefs about technology use will be developed and implemented; the collaboration of teachers that are using technology is essential for keeping excellent technology use (Becker, 1994); subjective norm- "Expectations of computer use from among teachers' significant others- principals, colleagues, students, and the profession" (Marcinkiewicz, 1994, p.522). Given their instructional goals, Watson (2006) mentioned that the teacher's belief in the value of technology as a pedagogical tool determines how technology is used. Armed with necessary computing skills, freedom in the curriculum, and convenient access to equipment, these teachers find computers a valuable instructional tool supporting their constructivist beliefs (Ertmer & Albion, 2009).

Ample empirical evidence shows positive results of technology use. Arkorful et al. (2021) found that technology use could also support crafting learning environments with greater interactivity among students and teachers and contribute to developing essential skills, such as critical thinking and learning in core domains, such as mathematics and science. Honey & Moeller, 1990; and Becker, 2000, 2001 found strong evidence supporting the relationship between technology use and constructivist practices (Sandholtz, Ringstaff, & Dwyer, 2000). In

addition, a study conducted on six teachers shows that, in general, teachers who hold more traditional beliefs tend to implement more traditional or "low-level technology uses, while teachers with constructivist beliefs tend to implement more student-centered or "high-level" technology uses (Judson, 2006; Roehrig et al., 2007). Teachers with more constructivist philosophical beliefs tend to use technology more frequently in challenging ways (Becker, 2001). On the student learning outcome, a significant number of experimental studies found positive, small to moderate sizes, effectiveness of teaching with the use of technology (e.g., Bernard et al., 2014; Cheung & Slavin, 2013; Tamim et al., 2011).

Regarding teachers' beliefs about teaching with technology in the Mathematics Classroom, Thurm & Barzel (2021) identified these sub-dimensions from literature. However, while being non-exhaustive, the list is found to have a pedagogical impact on mathematics teaching and learning. These include the beliefs about the role of technology in supporting discovery learning (Barzel & Moller, 2001). Technology can support the exploration of mathematical relationships. This can be achieved, for example, by generating examples and exploring patterns, providing students with the opportunity to learn mathematics as a constructive activity (Thurm, 2018), and beliefs about the role of technology in supporting multiple representations (Kaput, 1992; Duval, 2006). In this case, technology can be used to link different representations dynamically. Different forms of representation should be used in the classroom to build connections among them and facilitate conceptual understanding of mathematics.

A few glaring negative beliefs about teaching with technology are the high time requirement needed to teach or prepare lessons with technology (Cuban, 2004; Coffland & Strickland, 2004; Regalado & Smale, 2019). Some teachers believe that technology use results in

students' loss of computation or by-hand skills (Goos and Bennison, 2008; Thomas, Hong, Bosley, and Delos Santos, 2008; Handal et al., 2011). There are also those teachers who believe that technology encourages mindless work.

With these seeming contrasting claims, Schommer (1990) suggested that belief is multidimensional, which necessitates further investigation for illumination. This researcher felt it is appropriate to investigate a few beliefs related to teaching practice (i.e., modes of technology use) in the secondary mathematics classroom identified previously by Thurm and Barzel (2021), including teachers' beliefs about teaching with technology, epistemological beliefs, and self-efficacy.

**Teacher Belief Change for Behavior Change.**

Changing teacher beliefs is a complex process (Murphy, 2000), as beliefs can be static and resistant to change depending on how much it is tied to the teacher's identity. Ertmer (1999) argued that if beliefs are formed and developed through personal experience, then change in belief should also be affected through experience. Kagan (1992) proposed that teachers form ideas on which beliefs are based on practice, both their own and their peers, as it is generally unaffected by reading and applying research. In addition, Pajares (1992) suggested that **change in beliefs follows, rather than precedes, behavior change** and that newer beliefs are more likely to change. Teacher practice (i.e., use of technology) may lead to changes in belief about teaching with technology.

Windschitl & Sahl (2002) identified situations that effect change in teaching behavior as well as scenarios that inhibit such

> providing teachers with alternative visions of teaching with technology and opportunities to experience alternative approaches in supportive contexts… to observe peers working

> with technology and access mentors or coaching support as they implement changes in their teaching. Suitable models for observation are not widely available, and …even when schools release teachers from their classrooms for observation, it is expensive and disruptive…Even when suitable for schools…teachers are reluctant to initiate routine changes for fear of disadvantaging their students. (p. 165).

Thurm & Barzel (2020) found that professional development micro-teaching professional development experience of teacher jobs they perform when teaching with technology, such as "giving helpful feedback without explaining the solution," received positive feedback from teacher participants, indicating significant potential for teacher behavior change.

***Professional Development***. Richardson (1996) noted that in-service teachers' beliefs about teaching, learning, and content impact how they view professional development, what they learn from it, and how their teaching practice changes. A study on teachers' beliefs and the learning process during technology training shows that "greater correspondence between teachers' beliefs and training content led to greater learning" (Ertmer, 2010, p. 263). Because teachers value what allows them to meet students' needs, they are more likely to integrate technology if they believe it addresses essential learning outcomes (Ottenbreit-Leftwich, 2007). Teachers can more readily transfer that knowledge to their classrooms when they use technology within the specific content and grade levels taught (Hughes, 2005) and are more likely to integrate new technologies when they align with their existing beliefs (Ertmer, 2010, p. 263).

## Barriers

The idea of technology presents excellent promise. However, it has its challenges. Research has shown that many teachers are apprehensive about using technology in the

classroom. The reasons include two major categories: internal and external barriers. Some external barriers, like access to a connected device, are taken care of, at least in the United States. However, the issue concerning access to appropriate software and training in its use still needs to be addressed. Many professional developments are not specific enough to address teachers' need to implement instruction with technology confidently, and time to explore, create, and implement technology in teaching is glaringly wanting. Access to resources teachers find easy and readily accessible is also an issue.

It also presents a problem when students do not have access to the appropriate device or are not connected to the internet. In the United States alone, access to a smart device and the internet seemed universal but not uniform. For example, rural areas tend to have slower, non-WIFI mobile technologies, and counties with higher minority and older populations tend to use slower mobile technologies (McFarland et al., 2019). In addition, the NCES report in 2019 showed that lower-income families tend to access the internet using a smartphone and are therefore limited in terms of functionality, such as word processing or access to interactive learning platforms (masking the digital divide/inequities), impacting the ability as an educational tool.

To close the homework gap, the FCC spent $7.17 billion (about $22 per person in the US) on the emergency connectivity fund as part of the American Rescue Pal Act of 2021 (FCC, 2022) to help provide laptops, tablet computers, Wi-Fi hotspots, modems, routers, and broadband connectivity for out-of-campus use for students, teachers, and staff.

**Self-efficacy Theory (SET)**

Self-efficacy (or confidence) is a concept coined by Albert Bandura (1997), referring to an individual's belief in their capacity to execute behaviors necessary to produce specific

performance attainments. It determines "how people feel, think, motivate themselves, and behave" (Bandura, 1994, p.71). Self-efficacy beliefs affect life choices, motivation level, functioning quality, resilience to adversity, and vulnerability to stress and depression (Bandura, 1994). For example, individuals with high self-efficacy view complex tasks as challenges and bounce back quicker after failures and setbacks. They consider failure as a lack of preparation, insufficient effort, or knowledge, which are acquirable. Individuals with low self-efficacy tend to dwell on their deficiencies, focusing on adverse outcomes rather than overcoming and performing successfully. They take a long time to recover.

An individual's beliefs about efficacy can be developed through four primary sources of influence: mastery experiences, vicarious experiences, social persuasion, and physiological and emotional states. It allows individuals to interpret the outcome of their prior success or failure to judge their ability. These reduce stress reactions, negative emotional proclivities, and misinterpreting a person's physical state (Bandura, 1997). Mastery experiences are instances where a person has succeeded in a challenging task or overcome a failure/difficulty. In a 2018 study, Capa-Aydin et al. concluded that successful endeavors increase perceived self-efficacy while failures lower perceived self-efficacy, individuals also consider their vicarious experiences when they lack personal experience. They look at others as models or guides, observe them, and compare them to their perceived abilities. So, the more the individual feels like the model, the stronger their sense of self-efficacy becomes. Social persuasion is connected to positive feedback from influential people like parents, teachers, and peers, encouraging individuals to overcome self-doubts (Capa-Aydin, 2018). Furthermore, psychological, and emotional states influence self-efficacy. Bandura posited those feelings of anxiety, stress, fatigue, and positive/negative mood

impact self-efficacy. Moreover, of all these influences, Bandura (1997) asserts that personal mastery experiences are the primary determinants of behavioral change.

### *A Teacher's Perceived Efficacy*

A teacher's perceived efficacy or a teacher's beliefs about their ability to effectively handle the tasks, obligations, and challenges related to their professional activities plays a crucial role in influencing critical academic outcomes (i.e., student achievement and motivation) and well-being in the working environment (Barni et al., 2019). Creating learning environments conducive to learning rests heavily on the talents and self-efficacy of a teacher. (Bandura, 1997, p. 240). Teachers with a high sense of efficacy about their capabilities can motivate students and enhance their cognitive development. A teacher with a low sense of instructional efficacy favors a custodial role orientation that relies heavily on negative sanctions to get students to study (Bandura, 1994).

Teachers' beliefs in their efficacy affect their general direction toward the educational process and specific instructional activities (Bandura, 1997, p. 241). Melby (1995) It has more weight than their ability to transmit subject matter as its effectiveness is also partly determined by their efficacy in maintaining an orderly classroom conducive to learning, enlisting resources, and parental involvement in children's academic activities (Bandura, 1997, p. 243).

Teacher self-efficacy is a powerful drive that influences the behavior of a teacher in the classroom and the effort put into the endeavor (Klassen et al., 2009; Klassen & Tse, 2014). Improved self-efficacy can improve students' academic performance (Bandura, 1977). It was supported by a recent study by Thurm and Barzel (2021), concluding that "self-efficacy is a central construct for higher aspects of teaching mathematics and learning." However, numerous studies contend that it still lacks clarity, hence the skepticism (see i.e., Wheatley, 2005).

Existing research on self-efficacy needs to be improved to multi-items as they tend to be single items. It is also cast in general form rather than tailored to the instructional functioning domain. A teacher's sense of instructional efficacy is not necessarily uniform across different subjects. Thus, a teacher who judges himself highly efficacious in mathematics or science instruction may be much less assured of his efficacy in language instructions and vice versa (Thurm & Barzel, 2019). Therefore, "teacher efficacy scales should be linked to the various knowledge domains and … select those most germane to the domain of functioning the research is designed to elucidate" (Bandura, 1997, p.243). It is also true concerning a teacher's use of technology in teaching. Clark-Wilson and Hoyles (2019) found that low self-efficacy may affect a teacher's inconsistent plan to integrate technology into instruction. However, research is lacking in providing a nuanced explanation for this phenomenon.

**Epistemological (Epistemic) Beliefs**

A teacher's beliefs about the nature of mathematics and beliefs about mathematics teaching and learning are essential as they are argued to be powerful at impacting teaching. It serves as filters by selecting content and emphasis, teaching styles, and learning modes" (Ernest, 1989). A teacher holds multiple views about mathematics. Lerman's view of mathematics: (1) absolutist view of mathematics as universal, absolute, specific, value-free mathematical knowledge; and (2) fallibist view of mathematics as developing through conjectures, proofs, and refutations (Thompson, 1992; Philip, 2007). Ernest (1988) has three conceptions of mathematics: (1) a dynamic, problem-driven discipline; (2) a static, unified body of knowledge; (3) a bag of tools. Some teachers view mathematics as a static body of disconnected skills and facts that should be memorized or a set of ideas, strategies, or tools for solving problems (Xie & Cai, 2021). Another view that a teacher holds of mathematics includes two perspectives: (1) instrumental (mathematics

as a tool) and (2) structural (mathematics as a unified body of knowledge with structures and truths bound with logic and meaning). The instrumental view pays attention to the function of mathematical knowledge on the external world, while the structural view emphasizes the complexity of the internal structure of the knowledge itself (Ernest, 1988). A teacher's beliefs about mathematics relate to how he teaches mathematics and what mathematics to lead (Shommer, 1990). For example, a teacher who believes that math is a random collection of facts and procedures is more likely to emphasize memorization of facts and procedures. Likewise, a teacher who thinks math is a connected set of concepts that can be used to solve problems is more likely to give students opportunities to make connections (Xie & Cai, 2021).

A teacher's beliefs about mathematics learning refer to his beliefs about students' role in their mathematics learning and his perceived attributes of "good" learners. Similarly, a teacher's beliefs about teaching refer to his notions of the principles of classroom teaching and the nature of effective teaching. They include four views: learner-focused, content-focused with an emphasis on conceptual understanding, content-focused with a focus on performance, and classroom-focused (Ernest, 2989).

Research has indicated that regarding integrating technology in the mathematics classroom, teacher beliefs influence how and when technology is used (ChanMin et al., 2013). A teacher with a strong constructivist and dynamic perspective uses technology constructively (Thurm & Barzel, 2021). Ernest (1989) found some indication that beliefs about teaching mathematics were more influential in a teacher's practice than his belief about mathematics. This contradicts Thompson's (1992) findings that the relationship between the nature of mathematics and instructional practice is more consistent than beliefs about mathematics teaching and learning. ChanMin et al. (2012) found that the nature of knowledge, understanding, and thoughts about

effective ways of teaching were related to their technology integration practices. Thurm and Barzel (2021) found that ideas about the nature of mathematics were unrelated to self-reported modes of technology use. These findings of no consensus may indicate a lack of complete understanding of the nuances of how epistemic belief's role impacts the use of technology (Kim et al., 2013).

## Teachers' Qualifications and Characteristics

According to Hattie (2018), in his meta-analysis based on 1200 meta-analyses - up from 800 when Visible Learning came out in 2009 - the teacher is one of the most influential factors in student achievement, next to the student. Blömeke (2016) suggested that teacher quality (as measured by experience, level of education, and professional development) was related to some aspects of instructional practice. Contrasting findings indicate that teacher quality is not a statistically significant predictor of student mathematics and science achievement.

### *Years of teaching experience.*

Russell et al. (2003) found that technology use for different purposes differed across years of experience in teaching: teachers with 15+ years of experience used technology less than those with 6–15 years of experience. Xie and Cai (2020), in their study of four groups of Chinese mathematics teachers with varying years of experience, found that teachers with 6-10 years of experience were most likely to hold a more dialectic view of mathematics. On the other hand, Inan and Lowther (2010) reported a significant indirect effect of years of teaching on technology integration. Umugiraneza et al. (2018) found that teachers with less than ten years of teaching experience were likelier to use technology in the classroom.

### *Gender*.

Spotts et al. (1997) found in their investigation on technology use by faculty at a medium-sized university, public university in the midwestern United States that there was no significant

difference between female and male use of technology, except for the use of video where females indicated a slightly more frequent use. For factors related to influencing technology use, females rated time to learn a technology, increased student learning, ease of use, training, and available information on discipline as more important than males. Lack of time and lack of contribution to professional development were rated higher by women than men. On the other hand, Scherer and Siddiq (2015) found that female teachers' use of technology was reported to be lower than that of their male counterparts. Umugiraneza et al. (2018) found that male teachers are more likely to integrate technology into their educational practice than female teachers. These findings suggest that gender differences in the use of technology need to be addressed.

***Professional Development Training participations.***

Desimone et al. (2002), in a purposeful sample of about 207 teachers in 30 schools, found that professional development focused on specific instructional practices increases teachers' use of those practices in the classroom, particularly in active learning opportunities. Supovitz & Turner's (2000) findings indicate that the number of professional development teachers is strongly linked with inquiry-based teaching practice and investigative classroom culture. This is primarily true, provided the experiences are more profound and sustained. Both teaching practices and classroom cultures were influenced by rigorous and sustained professional learning activities (Supovitz & Turner, 2000). But at the individual level, teachers' content preparation also is a powerful influence on teaching practice and classroom culture, regardless of the extent of their professional development. Umugiraneza et al. (2018), in a study on seventy-five (75) KwaZulu-Natal mathematics teachers who use, access, and integrate technology in teaching and learning mathematics, found that the propensity to use technology in instructional practice is associated with demographic factors related to teaching experience, gender, level of study and participation

in professional learning activities. These diverging findings call for more research and draw attention to several demographic characteristics that correlate with teachers' instructional practice (i.e., the use of technology).

**A few learning Theories: Objectivism and Constructivism**

Many learning theories have been helpful in Mathematics education. These include behaviorism and constructivism. Behaviorism focuses on explicit teaching (direct instruction), where teachers begin the lesson by modeling the desired learning or introduction. The teacher then guides students through classroom problems (i.e., I Do, We Do, You Do) (Siemon et al., 2013). Constructivism is an inquiry-based lesson that involves an introductory activity that allows for connections between students' prior knowledge of mathematical content and strategies; it involves student reflection, an opportunity for teachers to assess student progress.

Behaviorist practices are more like recipe-based learning, which is focused on procedures and algorithm-heavy. Constructivism is focused on conceptual understanding. It focuses on students using prior knowledge of mathematical content and strategies. It is heavy on the student's reflection and checking on their learning progress. Both approaches are heavily criticized for being one-sided. A more dynamic and eclectic approach has been noted and observed in teaching practice.

Armed with newer capabilities coupled with changing societal demands, technology in the classroom has shifted from being a mere supplement. (i.e., to practice or as a tutor) to facilitate the teaching and learning process (i.e., conceptual development tool, simulation, multiple representations), shifting the teaching practices from solely teacher-centered (behaviorist) to a more student-centered (constructivist) or a combination of both. Technology tools like Desmos provide learning opportunities for students to explore mathematical concepts individually and

collaboratively with its embedded functionality for real-time response sharing. This allows students to learn independently first from peers and their teachers. In addition, it can provide skills practice with immediate feedback when intended as such. Because of its growing capabilities, it is observed that growing technology use in the classroom is more along the lines of constructivist implementations; hence, more discussion on constructivism is below. It has been noted in this paper that technology alone is no catalyst for change. But with its help, teaching and learning have become flexible. And teachers are found to hinder student-centered practices. There are many explanations for this, but evidence supports that teaching practice is influenced by student feedback and outcomes.

**Constructivism**

Constructivism is a learning theory that indicates that a person's knowledge is constructed by her or himself in some environment setting (Cottrill, 2003). This theory is based on Piaget's theory of learning, which emphasizes the stages of cognitive development theory demonstrating the different modes of thought at different ages, which are suggested for children to pass through in the same order. These stages include pre-operational, concrete, operational, and formal operational thinking. Piaget describes cognitive "epigenesis" as the process of assimilation and accommodation. This means a student can progress from one level of understanding to a higher level through reflective action.

Constructivism has many forms or variations, including radical and social constructivism. According to radical constructivism, a term coined by von Glasersfeld (1989), knowledge is not passive but is actively built by the cognizing subject. He further explained that knowledge refers to the viability of conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language (von Glasersfeld, 1992) and that the most common

source of perturbations for the developing cognitive subject is interaction with others (Glasersfeld, 1989). In addition, he defines learning as self-organization and acknowledges that this constructive activity occurs as the cognizing individual interacts with other members of a community" (Glasersfeld, 1992). This means that learning is not passive nor transmitted through communication.

Sociocultural constructivism, attributed to Vygotsky's sociocultural theory, views human development as a socially mediated process in which children acquire cultural values, beliefs, and problem-solving strategies through collaborative dialogues with more knowledgeable members of society (Innes, 2007). It focuses on meaning-making and is a central discussion of educational reform. Acknowledging the myriad of real problems that teachers face in the classroom, Vygotsky (1997) indicated how "Practice pervades the deepest foundations of the scientific operation and reforms it from beginning to end. Practice sets the task and serves as the supreme judge of theory as its truth criterion. It dictates how to construct the concepts and formulate the laws."

***Constructivism and Education-including Mathematics Education***

Cobb (1994) asserted that sociocultural and radical constructivists recognize that activities play a key role in mathematical learning and development. However, sociocultural theorists typically link activity to culturally organized practices, while radical constructivists emphasize individual students' sensory-motor and conceptual activity. Steffes and Kieren (1994) discussed von Glasersfeld's constructivist teaching experiment, originally a hybrid of Piaget and mathematics teaching that included conceptual analysis to build models of children's mathematical knowledge and its construction. Richards and von Galsersfeld's work differ from Piaget's in constructivism because it is about the structure of reality and not reality (Thompson, 2020). This has made modeling the primary means we distinguished between our activities as teachers and as

researchers in constructivist teaching experiments. Such models had both general and specific qualities, so “on the one hand, the model should be general enough to account for other children’s mathematical progress. On the other hand, it should be specific enough to account for a particular child’s progress in a particular instructional setting.” (Cobb & Steffes, 1983)

No matter which side of the coin, radical or sociocultural, the focus on student-centered learning is constructivism's most crucial contribution. In a 2015 study, Bada and Olusegun concluded that teachers need to reflect on their practice to apply these ideas to their work and that constructivist teachers encourage students to assess how the activity is helping them gain understanding constantly.

Honebein (1996) describes the seven pedagogical goals of constructivist environments as to provide experience with the knowledge construction process; to provide understanding in and appreciation for multiple perspectives; to embed learning in realistic contexts; to encourage ownership and a voice in the learning process; to embed in social experience; to encourage the use of multiple modes of representation and to encourage awareness of the knowledge construction process. However, it is known that the moment the constructivist philosophy is adopted in the day-to-day classroom practice, significant alteration occurs not only in terms of the physical arrangement of the workspace in the classroom or the use of “manipulatives” but the foundational view of what constitutes knowledge itself,… basic notions of what an acceptable student product or the nature of the mathematics so much so that “enabling the in-service and pre-service teacher to make use of technology with success poses a major challenge” (Wright & Wilson, 2011). Contrary to the traditional approach, constructivists view the learner as actively participating in the learning process. For example, Sivin-Kachala and Bialo (2000) reported that positive and consistent engagement patterns are observed. But just having technology does not necessarily

translate to enhanced student learning and performance (McNight et al., 2016). There is a need to employ instructional strategies that allow students to build on their own experiences, construct their meanings, create products, and solve problems successfully to prepare the active learner for the digital global economy of the 21st Century.

***Technology, constructivism, including Mathematics, Teaching, and Learning***

Recognizing that what may be perceived as relevant today may be rendered obsolete and useless tomorrow due to constant technological advancement could be the driving force behind Thurm and Barzel's (2021) finding that "one cluster of teacher beliefs that reflects a broader set of sub-dimensions is related to the more integrated and constructivist implementation of technology."

In addition, teachers could recognize the need for students to learn how to construct their knowledge through experiential learning instead of merely passively receiving it. This would help prepare learners to be productive creators of knowledge, a crucial contribution to the information-age society in which they will soon participate.

Geiger (2000b) suggested that the most significant changes of the introduction of technology are in student-teacher interaction or in the ways technology is embedded in the discourse in the collaborative learning environment (Simonsen & Dick, 1997). The use of graphing calculators' role in shifting the orientation towards student-centered, discursive, and exploratory approaches. However, some researchers (i.e., Bray & Tangney, 2017) suggest that digital tools with appropriate pedagogy to facilitate realistic, problem-solving, and collaborative approaches to teaching and learning and provide a coherent context for mathematics (Hoyles, 2015) have been found to not live up to their perceived potential to enhance the learning experience (Geiger et al., 2010) and perceived to be difficult and impractical to implement (Boddy et al., 2003).

These diverging findings warrant further investigation for better understanding as Shah et al. (2019) suggested that the constructivist approach can produce tremendous results when used correctly and judiciously; it can also lead to poor results and ineffective learning when misconstrued or misused.

## Summary

This chapter mentioned the extant literature relevant to the research questions this study investigated. It opened with the current condition and brief historical background of technology in mathematics education to provide context for the study. This is followed by the discussion of teacher beliefs known to play a potent role in teacher behavior (i.e., use of technology) and is broken into three multidimensional and sub-dimensional constructs: beliefs about teaching with technology, self-efficacy, epistemological beliefs, teachers' characteristics, and qualifications. Finally, a summary of behaviorism and a more extensive description of constructivism

This researcher was encouraged to investigate further in the hopes of adding to the body of research needing more consensus regarding the role of these multidimensional beliefs (e.g., teaching with technology, self-efficacy, and epistemic beliefs) in teaching behavior (e.g., mode of technology use). In addition, a mixed methods design is employed to make a finer-grained analysis to understand the phenomenon under investigation better.

# Chapter 3 - Methodology

## Introduction

The aim of this chapter includes (1) a description of the study's purpose and the questions to be answered, (2) a description of the methodology used in the study, and (3) a description of the research design utilized within the method. Multiple sections of the research design begin with a context on data collection: who, when, where, and how to gather the data. Next, a section on data analysis will include methods used to interpret the data, the steps taken to validate the data, how others can use the data and researcher biases.

## Overview/Research Design

### *Philosophical Assumptions of Research Design*

This study used a convergent mixed methods design, which involved simultaneously collecting, analyzing, and merging quantitative and qualitative data and results. According to Creswell and Plano (2018), the basic idea is to compare the two results to obtain a more complete understanding of the phenomenon, validate one set of findings with the other, or determine if participants respond similarly if they check predetermined scales and are asked open-ended qualitative questions.

According to Creswell & Plano (2018), **pragmatism**- the paradigm employed in this study- is well-suited for guiding the work of merging the two approaches into a larger understanding. Convergent mixed methods design intends to combine quantitative and qualitative data analysis results for comparison and combination. Convergent mixed methods design allows this researcher to determine the alignment of qualitative and quantitative results and teachers' reported beliefs and teaching practices how teachers' characteristics and

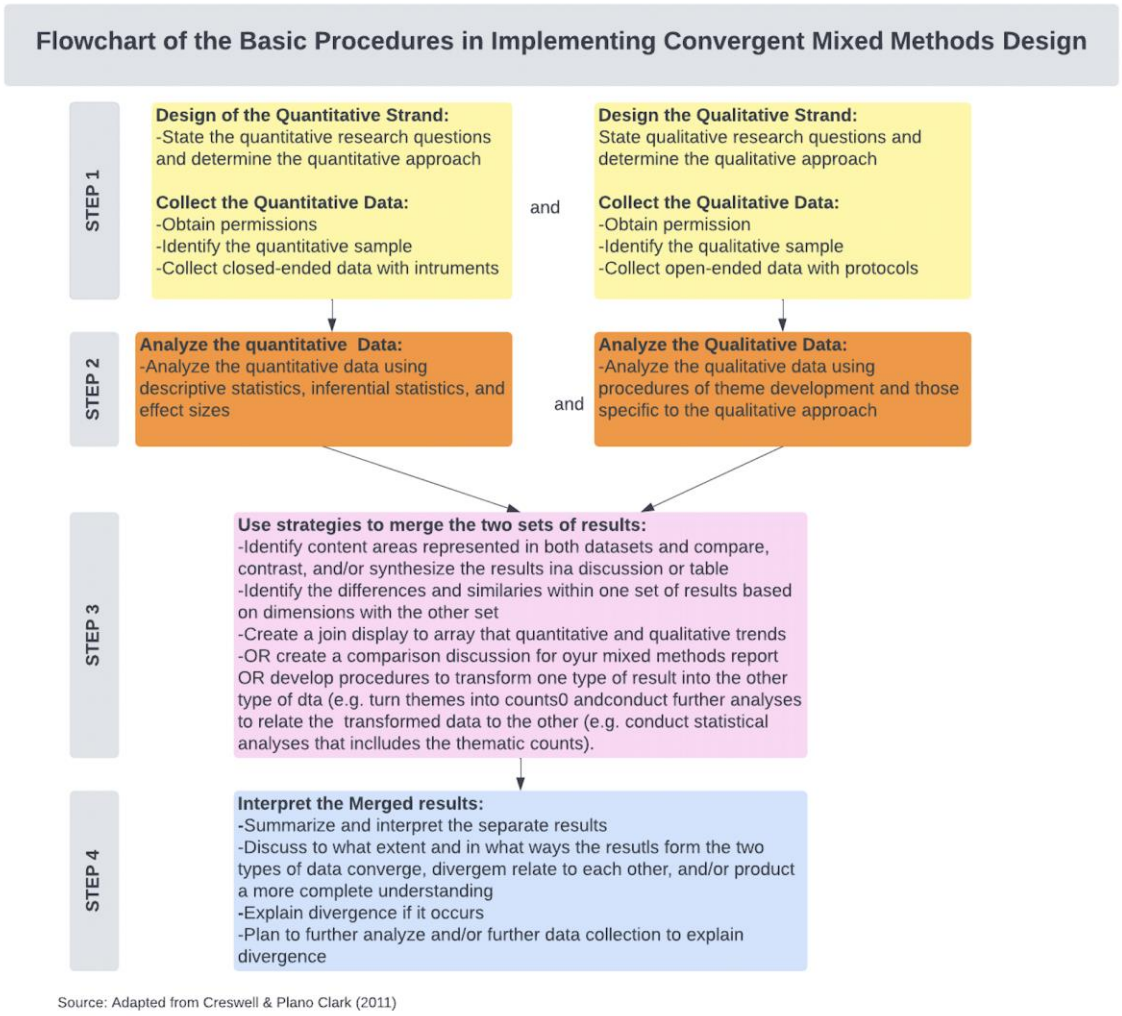
multidimensional beliefs of in-service secondary mathematics teachers align with observed teaching practice (i.e., the mode of technology use).

### *Why a Mixed Method Study?*

According to Creswell and Plano (2018), a combination of both forms of data provides the most complete analysis of complex problems. Research situates numbers in the contexts and words of participants, and it frames the words of participants with numbers, trends, and statistical results. Both forms of data are necessary. Mixed methods are intuitive for many as they mirror the types of evidence that we collect to make sense of the world.

Figure 3.1.

*Flowchart of the Basic Procedures in Implementing Convergent Mixed Methods Design*




With this, my study has two strands: the quantitative and the qualitative strand. Each strand is described separately.

**The Quantitative Strand**

The quantitative strand of the study was designed to understand the relationship, strength, and direction of teacher characteristics, multi-dimensional beliefs, and how technology is used in

teaching and learning mathematics in the classroom. This anonymous survey included 76 Likert scale questions (strongly agree, somewhat agree/agree, neither agree nor disagree, somewhat disagree, and strongly disagree; always, most of the time, sometimes, rarely, never). 116 middle school and high school Mathematics teachers from a large district in the Midwest USA participated in the survey. Of the 116, only 83 completed the survey. While it is unfortunate that this response rate is only 39%, which is 5% below the typical response rates of online surveys according to the conclusion of a meta-analysis conducted by Wu, Zhao, and Fils-Aime (2022), I believe that as a whole, the collected data will provide us with information on the current state of teachers belief in technology use in teaching mathematics, self-efficacy beliefs, and epistemological beliefs in relation to teachers mode of technology use.

***Setting/Context or Population Sample***

The target population for this quantitative strand was secondary mathematics in-service teachers of a large district in the Midwest USA. A brief background: in the SY 2021-2022, the school district implemented 1-1 technology so that all students, especially middle school, and high school students, have a school-issued laptop, including a mobile internet device for those who need it. According to the NCES report for SY 2020-2021, this district has eighty-eight (88) schools employing about 4,584 teachers (FTE) and about 1683 secondary teachers. The total number of students is 46,908; the student-to-teacher ratio is approximately 10:1.

***Participants***

Eighty-three (83) secondary mathematics teachers, 48 of whom are high school teachers and 35 of whom are middle school teachers, completed the survey. All the teachers volunteered to participate. The participants were informed that the survey was anonymous. To encourage

participation, the participants were offered a $15 Starbucks gift card if they left their email at the end of the survey.

Figure 3.2 below shows a pie chart of teacher participants' grade level taught. 58% are high school teachers, and 43% are middle school teachers. The grade level taught, and educational attainment have the same distribution; 58% are middle school and undergraduate.

**Figure 3.2.**

*Pie Chart of Teacher Gender, Grade Taught, and Education*

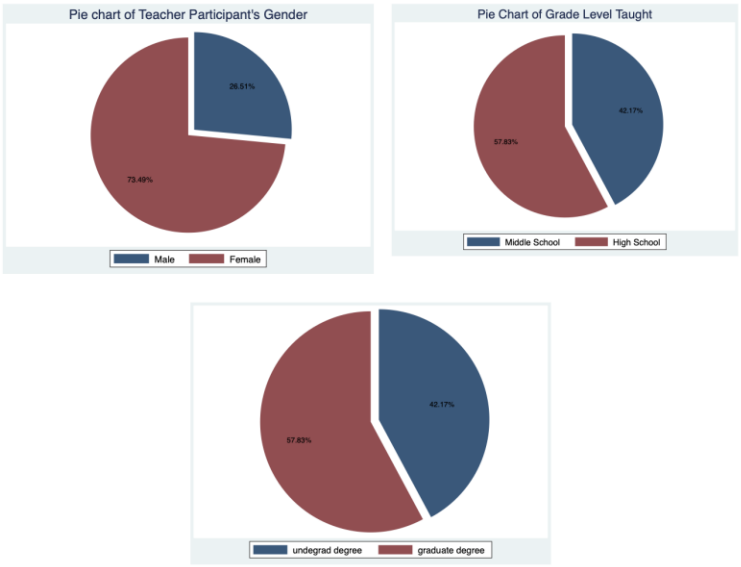



**Figure 3.3.**

*Bar Graph of Teachers' Race and Certification Status*

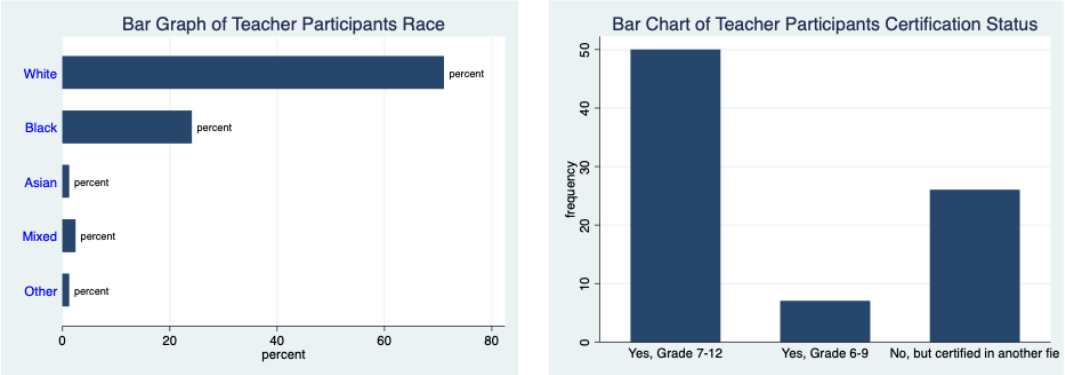
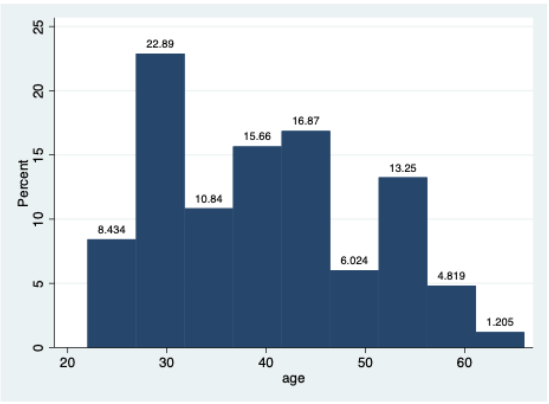
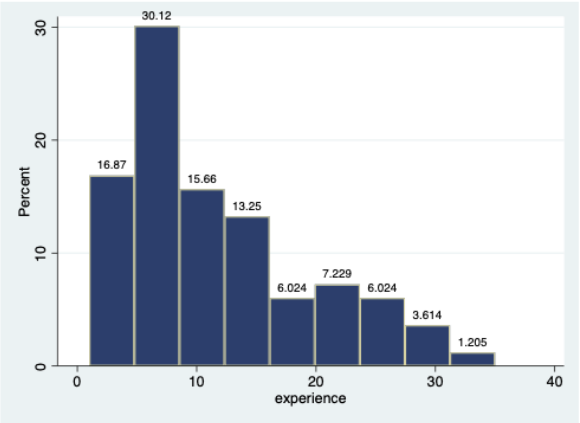
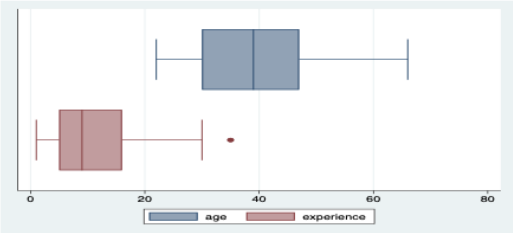


**Figure 3.4.**

*Graphical Display and Number Summaries: Teachers Age and Years of Experience*




| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Age | 83 | 39.59 | 10.604 | 22 | 66 |
| Experience | 83 | 11.313 | 8.042 | 1 | 35 |

***Research Questions***

The primary research question for this quantitative strand includes "What teacher characteristics (gender, age, teaching experience, educational level) and multidimensional beliefs (b*eliefs about teaching with technology*, *self-efficacy beliefs, epistemic beliefs*) are associated with the mode of technology use in teaching math in the secondary classroom?"

The secondary questions are as follows:

SubQ1: To what extent, strength, and direction are teacher characteristics associated with the mode of technology use?

SubQ2: To what extent, strength, and direction are teachers' multi-dimensional beliefs about teaching with technology associated with the mode of technology use?

SubQ3: To what extent, strength, and direction are teacher epistemological beliefs associated with the mode of technology use?

SubQ4: To what extent, strength, and direction are self-efficacy beliefs associated with the mode of technology use?

### *Sampling Techniques*

A voluntary sampling method- a type of non-probability sampling- was employed. Volunteers choose to complete a survey. Volunteers were invited through an email distribution list from district personnel. In this way, every secondary mathematics teacher in the district received an email with a QR Code and a link to an electronic survey created via Qualtrics. Due to the nature of the voluntary sample, anticipated response bias exists because participants who self-choose may have a strong opinion towards the subject compared to those who did not participate. In addition, undercoverage bias is also expected since most population members may need to be sufficiently represented in the sample. With this, caution with generalization and inferences is imperative. Because of the sampling technique, this researcher's conclusions and interpretations were limited only to the study participants and those with similar situations and avoidance in making implications for the general population of secondary mathematics teachers or teachers.

This survey collected demographic information relevant to the research question. Some critical features shared by the group were identified by taking as many teachers as possible.

### *Data Collection*

An existing survey instrument created by Thurm (2017) was used to measure teachers' multi-dimensional beliefs on a) beliefs about teaching with technology, b) self-efficacy beliefs, c) epistemological beliefs, and d) modes of technology use. To participate, an email invitation was sent to all Inservice secondary mathematics teachers using the district's employee

distribution list. The data collection took place between March 2023 and May 2023. The quantitative survey will be administered via the web-based software Qualtrics.

### *Variables*

The study's predictor variables will be teacher characteristics (gender, age, years of experience, level of education) and the teachers' multidimensional beliefs (beliefs about teaching with technology, self-efficacy beliefs, epistemic beliefs). The response variable will be the mode of technology use (discovery learning, multiple representation, drill and practice, individual learning, and reflection), which will be measured in frequency of use.

### *Data Analysis*

The quantitative strand aimed to identify the explanatory power of teacher characteristics and multi-dimensional beliefs of secondary Inservice mathematics teachers in relation to teaching practice (i.e., mode of technology use). The data collected was analyzed using descriptive statistics, correlational analysis, and multiple regression analysis.

### *Pilot Study Report*

The pilot study informed the quantitative method, such as a low survey participation rate; hence, outcomes may need to be more reliable to provide valuable and meaningful answers to the research questions. This realization underscores the importance of employing mixed methods.

### *Reliability and Validity*

Reliability refers to the extent that the instrument yields the same result over multiple trials. Validity is the extent to which an instrument measures what it was designed to measure. To measure teachers' beliefs about a) teaching with technology, b) self-efficacy belief, c) epistemological belief, and d) modes of technology use, I used the survey instrument that Daniel

Thurm developed in 2017, which was the instrument used in a quantitative study of 198 upper secondary Inservice teachers in Germany by Thurm and Barzel (2021).

To measure teacher beliefs about teaching with technology, the multi-dimensional questionnaire with subscales includes common subdimensions of teacher beliefs about teaching with technology. Scales (T1) and (T2) address the potential benefits of technology use (i.e., technology supports multiple representations), while scales (T3), (T4), and (T5) refer to perceived barriers of technology use (i.e., technology encourages mindless working). Scales (T6) determine whether the teachers believe that technology should only be used after students already learned mathematics without it, which is highly linked to the Black-Box/White-Box principle in the order in which technology use is explained. Each item was rated on a 5-point Likert scale ranging from 1=" strongly disagree" to 5=" strongly agree."

The questions measuring teachers' self-efficacy beliefs have two categories: (S1) task design and selection and (S2) lesson design and implementation. Each item is scaled on a 5-point Likert scale ranging from 1=" strongly disagree" to 5=" strongly agree." The reliability coefficients of all scales were good, ranging from 0.90 to 0.92

Epistemological beliefs were measured using the scales from the international TEDS-M study. Subscales (E1) and (E2) focus on teacher beliefs about the nature of mathematics; one subscale refers to the static perspective (E1, "mathematics as a rule and procedure"), and one subscale refers to the dynamic perspective (E2), "mathematics as a process of inquiry"). Subscales (E3) and (E4) focus on teachers' beliefs about the learning of mathematics. While subscales (E3) focus on learning mathematics through teacher direction, subscales (E4) target teachers' beliefs about learning mathematics through active learning. Responses were given on a 5-point Likert scale ranging from 1=" strongly disagree" to 5=" strongly agree". The reliability

coefficients of the scales ranged from 0.60 to 0.76, which is reliable. In the qualitative strand, an initial interview, a semi-structured follow-up interview, and class observation will be helpful in data triangulation and understanding the varied factors and context to help answer the research questions.

**The Qualitative Strand**

The case study method is well-suited for the needs of this strand of inquiry to describe how teachers' beliefs drive technology use in teaching and learning mathematics in the classrooms. Stake (1995) suggested that the "first obligation" (p.4) in case study research is to develop and fully understand the case at hand. Case studies are appropriate when "closely examining people, topics, issues, or programs" (Hays, 2004) are necessary. The bounded system is the term used to define the focal point of the study (Stake, 1995). The bounded unit for this study is secondary mathematics teachers (i.e., high school) who use digital mathematical technologies to teach and learn math.

Yin (2018) provides three types of case studies: exploratory case studies, explanatory case studies, and descriptive case studies. Exploratory case studies define the framework of future research. Fieldwork and data collection are undertaken before the final definition of study questions and hypotheses (Yin, 2018). However, explanatory case studies seek to define how or why an experience took place. The purpose is to suggest the possibility of cause-effect (Yin, 2018). Due to its nature of claiming causality, this case study risks being challenged because one case does not make for a "true" experiment. Lastly, the descriptive case study is employed to develop a document to fully illuminate the intricacies of an experience (Stake, 1995). These present answers to questions based on theoretical constructs (Yin, 2018).

The descriptive study will be appropriate for two reasons: First, all case study research aims to develop an understanding of the bounded system. The primary purpose of this research is to understand how secondary mathematics teachers' mode of technology use is affected by teachers' multi-dimensional beliefs (i.e., self-efficacy beliefs). Secondary (i.e., high school) mathematics teachers may use the study results to understand better what teaching and learning mathematics using technology looks like from an outsider's perspective. This teacher may then use this insight to adjust their teaching practices to meet their needs. In addition, the administrator in the building may use the results to share an example of observable teacher practices available at school about technology use in math instruction with the community, the school board, or the school district.

Yin (2018) points out that case study inquiry is only successful when built on collecting and analyzing data from multiple sources. He also said, "Case studies can be a mix of quantitative and qualitative evidence" (Yin, 2018). So, the triangulation of data, both qualitative and quantitative, should lead to a credible understanding of the case. A single-case study with four (4) participants was used to collect and analyze the data to "illuminate a particular issue" (Creswell, 2005, p. 439), such as self-efficacy beliefs in relation to self-reported mode of technology use. The unit of analysis is the group participants. The initial interview was administered via email. The semi-structured follow-up interview was conducted via face-to-face interview video recorded on Zoom and class observations of 4 secondary math teachers who use technology to teach mathematics.

***Setting***. The NCES report for SY 2021-2022 indicated that the high school of the teacher participants qualifies as a regular school rural fringe (also known as outskirts, urban, peri-urban, or the urban hinterland). A rural fringe is a census-defined territory less than or equal to 5 miles

from an urbanized area. It is a Title 1 school with a Title 1 school-wide program. 100% of the students in the school are bused. 121 classroom teachers (FTE) had an approximately 16:1 student-to-teacher ratio. There were 1967 students (470-9th graders, 537-10th graders, 496 11 graders, and 464-12th graders). Of which about 28% (551) of the students were Hispanic, 29% (574) were Black, 19% (383) were White, 14% (266) were Asians, 9% (174) were two or more races, less than 1% (13) were American Indian/Alaskan Native, and less than ½% (6) were Native Hawaiian/Pacific Islander. Enrollment by gender is 51% (988) male and 49% (979) female; about 64% (1250) were free lunch recipients and 12% (232) were reduced-price eligible. The school's enrollment number is about 2200, about 18% (400) more students than the building capacity.

***Participants.*** The study population was the secondary (middle and high school) math teachers at a large school district in the Midwest. A purposeful sample of 4 high school mathematics teachers was recruited via email or a personal invite. The criterion is that the math teacher uses technology in mathematics instruction. Limiting the data collection to 4 high school mathematics teachers will help with data management. Yin (2018) points out that investigators who attempt to cover everything will soon find they are trying to accomplish the impossible. The data will be collected using an initial interview followed by a semi-structured follow-up interview and classroom observation. Table 3. provides a reference for a holistic picture of data collection. Each sub-question will be in the left-hand column of the table. In line with each sub-question are sources for the data, the method for data collection, and the method of analysis.

***Research Questions***

SubQ5: How do teachers' characteristics and multi-dimensional beliefs translate into classroom practice (i.e., mode of technology use) in teaching and learning Math?

SQ6: What are the barriers to incorporating technology in teaching and learning Math?

**Table 3.1.**

*Research Design Plan for the Qualitative Strand*

| **Question** | **Source(s)** | **Method(s)** | **Analysis** |
|---|---|---|---|
| SQ5: How does teachers belief translate into classroom practice (i.e., mode of technology use) in teaching and learning Math? | Teachers | Observation<br>Interview<br>(Initial and Semi-structured follow0up Interview) | Thematic Analysis |
| SQ6: What are the barriers in incorporating technology in teaching and learning Math? | Teachers | Observation<br>Interviews<br>(Initial and Semi-structured follow-up Interview) | Thematic Analysis |

### *Data Collection*

**Initial Interview**. The initial interview was administered for each of the teacher participants before conducting a classroom observation and another time as a culmination (debriefing) to help understand responses to the study and the observed behaviors during class observation that might help answer research questions that need more input for accurate interpretation. The follow-up interviews were 30-45 minutes, depending on the teacher. Each interview was held privately after school or when both parties were available. Teachers were not compensated for their participation.

**Semi-Structured Follow-Up Interview.** Stake (1995) suggested that “qualitative researchers take pride in discovering and portraying the multiple views of the case.” While observation allows the researcher to collect rich qualitative and quantitative data, it only allows the researcher's interpretation of the environment. Stake, therefore, suggested that "the interview is the main road to multiple realities" (p. 64). Biken (1992) thought that using the participants’ words could help the researcher develop an insight into others' understandings of the environment, including feelings, attitudes, thoughts, experiences, judgments, and intentions.

It is crucial to elicit the participant's views, especially their views of the study. One way to acquire pertinent data is to interview conversationally with open-ended questions, following the protocol based on research questions (Yin, 2018). LeCompte and Schensul (1999a) emphasized that "interviews follow the format of a formative theoretical framework and explore the main domains of the study, initial hypotheses, and contextual factors related to the study" (p. 123). The researcher must elicit facts, opinions, and insights about specific events. Researchers must remember that a good interview allows the subject to tell his or her story in his or her own words.

Otherwise, it is not qualitative anymore (Biken, 1992). LeCompte and Schensul (1999a) remind us that a good interviewer must (1) remember how the topic relates to and illuminates the more critical questions asked in the study. (2) Determine whether the person interviewed is staying on topic, and if not, how to reintroduce the topic. (3) Make sense of the connections and links that the interviewee makes. (4) Probe the meaning of vocabulary words. (5) Be aware of whether the interviewee's ideas are crystal clear and when they need elaboration so that anyone who reads the notes or transcript can understand them.

The researcher will conduct an initial and final interview following the above-stated suggestions for complete understanding. These interviews will address all research questions

(refer to Table 3.1). Lapan (2004) suggested that "testing the instruments in the field is essential to their readiness for use" (p. 241). He added that testing allows the beginning researcher to practice conducting interviews. They will be pilot tested to ensure the interview protocols are ready for use. Knowing this, I ensured that upon pilot testing each instrument, I adjusted the instruments based on feedback and realizations.

**Interview Mode and Transcription.** The follow-up interview was conducted either face-to-face or via video conferencing via Zoom. Either way, the interview was audio-recorded and transcribed on a password-protected Zoom. Both the transcribed and printed-out data transcripts are stored in a safe location. Personal identifying information was redacted from the stored documents to protect confidentiality.

The initial interview data was also stored in a safe location, and the electronic versions are stored in a password-protected account that only I can access.

**Classroom Observation**

Participant observation is "a process of learning through exposure to or involvement in daily routine activities of participants in the research setting" (LeCompte & Schensul,1999a). They added that observation is an essential component of research as it allows the researcher to understand the organization, prioritization, rules of etiquette, and relationships among members. Hays (2004) mentioned that observations are essential to case study research, especially in school environments where interactions could be challenging to understand.

Data comes from formal and informal observations (Hays, 2004). The formal observation "usually includes tallies of different types of observed behavior" (Hays, 2004), especially for quantitative data. On the other hand, informal observations allow the researcher to observe the environment and record its intricacies openly.

Due to the limited frequency of classroom observations, this researcher used field notes to collect data. This is a change from the proposed method of collecting data, which was guided by the idea of capturing the actual classroom occurrences, providing more context than using frequencies alone. In this way, I focused on the teacher's behaviors pertinent to my research questions.

### *Data Analysis*

Stake (1995) pointed out a concern with qualitative case studies' subjective tendency: They rely too much on the researcher's interpretations. This concern applies when the researcher conducting the case study methodology fails to ensure a quality approach to research and analysis processes. Therefore, procedures must be followed to create a quality product so that even an expert researcher finds difficulty discovering faults with findings. Below are data analysis measures to develop credible and meaningful results for this research.

According to Yin (2018), a "case-based" approach to cross-case synthesis is a quantitative-reductionist approach that helps identify critical variables and then aggregate the cross-case data for each variable. The goal is "to retain the integrity of the entire case and then to compare or synthesize any within-case patterns across the cases" (Yin, 2018).

Because I did not have many observation opportunities, I found it more meaningful to fill out the classroom observation protocol and make notes of the teacher's behavior that directly addressed the research question. This change allowed for vivid data extracts and insights that helped interpret the results.

**Thematic Analysis.** According to Braun & Clarke (2022, p. 8), thematic analysis is a method for developing, analyzing, and interpreting patterns across a qualitative data set. It involves systematic data coding processes to develop **themes**- the ultimate analytic purpose. As a

researcher, it is essential to undergo a reflective process. Reflexivity involves the practice of critical reflection on my role as a researcher and the research practice and process. Reflexive thematic analysis captures approaches fully embedded within the values of the qualitative paradigm, which then informs research practice (Braun & Clarke, p. 8). It comes in various forms: orientation to data, focus on meaning, qualitative framework, and theoretical framework. There were six phases to reflexive thematic analysis, including (1) data familiarization, (2) coding and (3) generating initial themes, (4) developing and reviewing themes, (5) refining, (6) defining and naming themes and writing up (p. 35). I summarized the process in two categories—the first four phases- the initial code creation, and the last two- the axial code creation.

**Initial Codes.** To familiarize myself with the data, I read and reread the written data responses. I also listened to my audio recordings with the transcripts a few times, alongside reading the transcript to capture what was said accurately. This process helped me take notes of insights about the current data item or the data aggregate. As I was reading the data, segments of data that were either interesting or meaningful were identified, given the research question. Code labels- brief but meaningful data descriptions- were then applied. Initial themes were generated from a cluster of codes that shared the same concept or idea that helped answer my research questions. This process was iterative. I probably had 5-6 versions of this before I felt comfortable with the outcome.

**Axial Codes.** I was developing and reviewing themes, checking that the initial themes still made sense about the coded extracts and the complete data set. I kept asking myself if the themes tell convincing and compelling stories about essential patterns of shared meaning across the dataset. And whether the themes highlight the most important patterns across the dataset. I

later decided to collapse, discard, split into themes, or create subthemes (axial coding) as I tried to relate the themes to my research question, existing knowledge, or when I reflected on my personal experience in the field as a high school Mathematics teacher. Using the question, “What story does this theme talk about my data?" as a guide helped me “refine, define and name themes” (p. 36). And then, finally, the write-up of coherent and persuasive paragraphs. I aim to weave together vivid data extracts (i.e., quotes) to tell a compelling story about my data.

**Table 3.2.**

*Axial Coding*

| RQ | THEME | SUBTHEME | CODES |
|---|---|---|---|
| How does a teacher’s belief translate into classroom practice (i.e., mode of technology use) in teaching and learning Math? | Teachers’ self-efficacy beliefs about technology align with their classroom practice | | - Confident with technology<br>- Moderate to high comfort with technology<br>- More confident with experience<br>- Student teaching positive effect on tech use<br>- Benefits of in-service training<br>- Teachers collaborate/help one another |
| | Teachers’ beliefs about how math should be taught may direct their adoption of technology in the classroom | Teacher-centered instructors used technology as an instructional supplement | - Teacher direction<br>- Teaching is clarifying/minimizing misconceptions<br>- Teaching is encouraging/confidence building<br>- Teaching is explicit instruction<br>- Teaching using examples<br>- Teaching using real life object or models<br>- Teaching using relevant tasks<br>- Students need context<br>- Teaching supports mastery learning |
| | | Student-centered instructors use technology to facilitate learning | - Multiple representations<br>- Teacher role as guide-facilitator<br>- Helping students see value in math/buy-in<br>- Teaching is providing opportunities for practice<br>- Technology fosters student engagement |

| | | | |
|---|---|---|---|
| | If teachers believe technology fosters positive teaching practices, they are more likely to adopt | General benefits to teaching practice | - Benefits about technology<br>- Technology fosters innovative lesson planning and instruction<br>- Technology as an additional resource<br>- Technology gives teacher freedom<br>- Technology saves time<br>- Technology for practice |
| | | Discovery learning | - Technology for concept exploration<br>- Technology for self-directed learning<br>- Technology use to access prior knowledge<br>- Technology use for conceptual building<br>- Technology as communication tool<br>- Technology use to foster collaboration<br>- Technology use to access content in various ways<br>- Deltamath<br>- Desmos<br>- Graphing calculator<br>- Document camera<br>- Preferred technologies<br>- Software (Mathia) |
| | | Multiple representation | - Technology for representing concepts in various ways<br>- Technology fosters different ways to prove learning |
| | | Tool for manual or mental calculation | - Technology for practice<br>- Technology use for immediate feedback<br>- Technology use as an assessment tool<br>- Technology use for computation<br>- Technology encourages students to check for accuracy |
| | | Individual learning | - Technology use for individual learning<br>- Technology is inclusive<br>- Technology use as presentation tools |
| What are the barriers in incorporating | Barriers internal to the teacher | | - Discomfort<br>- Lack of tech courses during teacher prep |

| | | | |
|---|---|---|---|
| technology in teaching and learning Math? | | | - Limited technology teacher training<br>- Need for math specific technology courses<br>- Need for training |
| | Barriers external to the teacher | | - Need for resources<br>- Limited technology access<br>- Time limitations<br>- Technology is expensive<br>- Technology is difficult/not helpful<br>- Overall lack of balance<br>- Limited technology access |

**Consistency and Trustworthiness**

***Validity***. Validity refers to the accuracy and trustworthiness of instruments, data, and findings in research. (Bernard, 1995) asserted that nothing in research is more important than validity. Creswell and Miller (2000) call validity a lens established using the view of people who conduct, participate in, or read and review a study. Guba and Lincoln (1994) labeled three paradigm assumptions: postpositivist, constructivist, and critical influence. In the case of the constructivist (interpretivist) paradigm, the criteria are called trustworthiness. According to Roberts (2020), the test of trustworthiness includes credibility, transferability, confirmability, and dependability.

***Credibility.*** Credibility tests the researcher's interpretation of the data (Charmaz, 2005). In this study, data triangulation will help check data convergence from multiple methods for data collection (refer to Table 3.1). The data collection includes an initial interview via email, a semi-structured follow-up interview, and classroom observation. Lincoln and Guba (1985) describe member checks as "the most crucial technique for establishing credibility " (p. 314 in a study. Creswell and Miller (2000) describe member checking as taking the data and interpretations back to the participants so they can confirm the credibility of the information and narrative account. Each teacher participant gets to read through the findings for their data. And in the process, the teacher participant will be encouraged to provide feedback. Denzin (1989) talked about thick,

rich descriptions- describing the setting, the participants, and the themes of a qualitative study in rich detail is another way to establish credibility. He suggested that " thick descriptions are deep, dense, detailed accounts" (Denzin, 1989). This aims to create authentic statements that produce the readers' feelings about what they have experienced, or events described in a study. The teacher participants in this study were asked to review the data and findings and provide feedback.

***Dependability and confirmability***. According to Lincoln and Guba (1986), dependability is the repeatability of the study within the same cohort of participants, coders, and contexts. Confirmability is developing a logical understanding of the data that corroborates with other researchers (Lincoln & Guba, 1986). Pilot and field testing of data collection instruments will be necessary to achieve dependability. This process will help ensure that the data received, and questions asked are consistent.

Both dependability and confirmability can be tested through investigator triangulation. Thick descriptions of the study, investigator triangulation, establishing an audit trail, and reflexibility are common strategies. Peer reviewers' feedback and reactions to the statements help develop consistency. In this study's case, I had a colleague help me confirm the appropriateness of my codes and themes. This peer review helped me decide on the fit of my codes or themes based on the highlighted data segments. This process also resulted in the revision of themes and the creation of subthemes based on the research question, existing knowledge, or personal field experience. The brainstorming sessions allowed me to think aloud, which helped me connect ideas and concepts even more. The classroom observation protocol was field-tested in a STEM classroom, which changed how data was collected.

**Researcher Reflexibility or Bias.**

According to Creswell and Miller (2000), it is crucial for researchers to self-disclose their assumptions, beliefs, and biases. Reflexibility is when researchers report on their personal beliefs, values, and biases. Acknowledgment and description of their entering beliefs and biases early in the research process to allow readers to understand their position, and then to bracket or suspend those research biases as the study proceeds" (Creswell & Miller, 2000, p. 127). To confirm that the findings are neutral, I will bracket my point of view (Roberts, 2020) (refer to Appendix C).

**Transferability or naturalistic generalization.** Transferability relies on the context-dependent judgment of 'fit' between two or more case instances made by a researcher (Hellstrom, 2008). Hellstrom (2008) further cited that it depends on the degree of fittingness, and to establish fittingness, a researcher must know both (all) situations between which knowledge is to be transferred. Transferability is a quality of knowledge in a particular communicative situation. Fittingness is a quality applied to a relation between situations.

Stake (1995) suggests that generalization is not the purpose of the case study; it is more of “particularization.” Particularization, as the purpose of the research, is not to compare it to multiple cases. Therefore, this research's primary purpose is not to define findings that may be transferable to other learning environments. But to deeply describe the unique teaching and learning environment in the Math classroom, how and why a teacher's technology use is linked to the teacher’s belief (i.e., self-efficacy, epistemic belief, and belief about teaching with technology). Hence, in this case, the readers may be secondary school mathematics teachers working to understand how to better their technology integration practices. Administration may be a reader trying to understand how to support secondary math teachers in their technology integration practices given professional learning opportunities offerings.

## Mixed methods

The goal of integrating the quantitative and qualitative strand analysis was to compare each strand's results. A finer-grained analysis helped identify patterns and trends and confirm or add new knowledge that helps in understanding the phenomenon of technology use in the mathematics classroom and, for example, providing contextual information for this particular teacher behavior (i.e., mode of technology use), reported or observed, including barriers and needs that may be useful to inform practice and policy, professional development offerings, and teacher preparation programs, among other things.

### *Research Question*

The mixed methods question is: How do the survey and case study findings align? This concerns the role of secondary mathematics teachers' characteristics and multidimensional beliefs in teaching practice (i.e., mode of technology use).

### *Demographic Information: Survey vis-à-vis Case Study Participants*

The survey was administered to secondary (middle and high school) mathematics teachers, while the case study participants were only high school teachers. This occurred due to work limitations the researcher did not anticipate but encountered while inviting participants and during data collection.

Figure 3.5 shows the overall distribution of teacher age and experience. In Figure 4.18, teacher survey respondents show a somewhat skewed trend toward older and more experienced teachers. However, the distribution of just high school teachers is somewhat symmetric and more evenly distributed across years (age: 20-65 years) and (experience: 0-35 years), consistent with the distribution of teacher ages and experiences from the case study data.

**Figure 3.5.**

*Boxplot and Histogram: Teacher's Age and Experience*

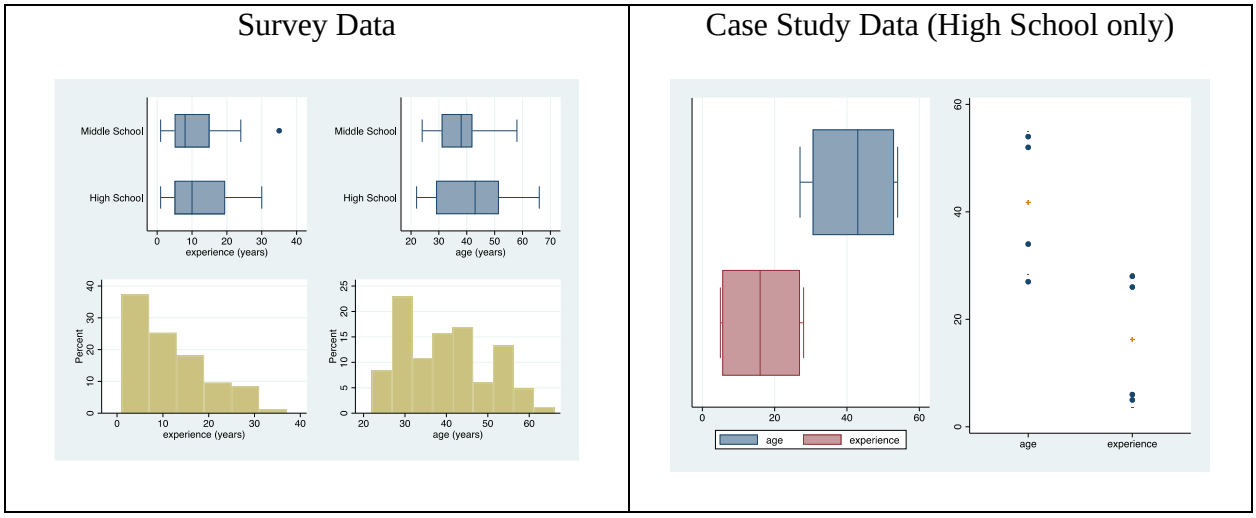



Figure 3.6 shows the teacher survey participation of 73% (61) female and 27% (22) male, which is similar to the distribution of the case study teacher participants, who were 75% (3) female and 25% (1) male.

**Figure 3.6.**

*Pie Chart for Teacher Gender*

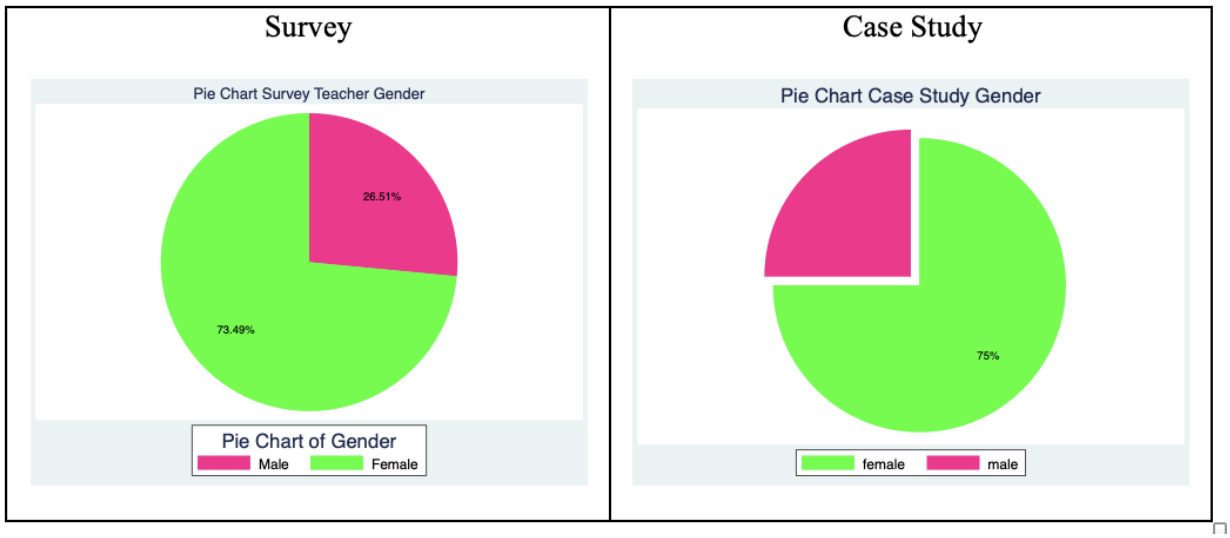
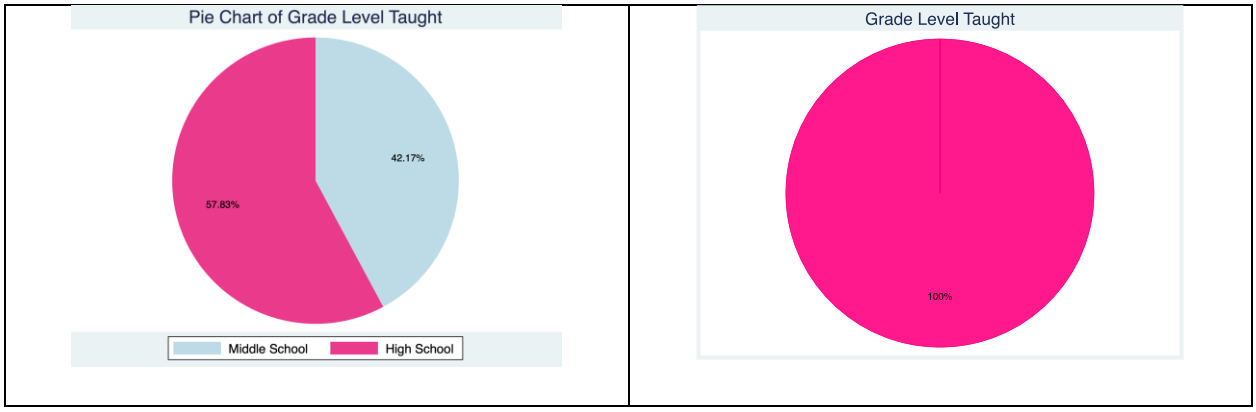


Figure 3.7 shows that while the survey respondents were comprised of 42% (35) middle school teachers and 58% (48) high school teachers, the case study participants were 100% (all) high school teachers. This discrepancy in grade-level participation is noted.

**Figure 3.7.**

*Pie Chart for Grade Level Taught*




Figures 3.8 show that of the survey participants, over 60% (50/83) teachers are certified to teach Grade 7-12 Math, 8% (7) Grade 6-9 Math Certified, and about 34% (26) are non-Math Certified but certified in other subject areas. All case study participants were Math certified: 75% (3) Grade 7-12 Math and 25% (1) Grade 6-9 Math.

**Figure 3.8.**

*Pie Chart for Teacher Certification Status*

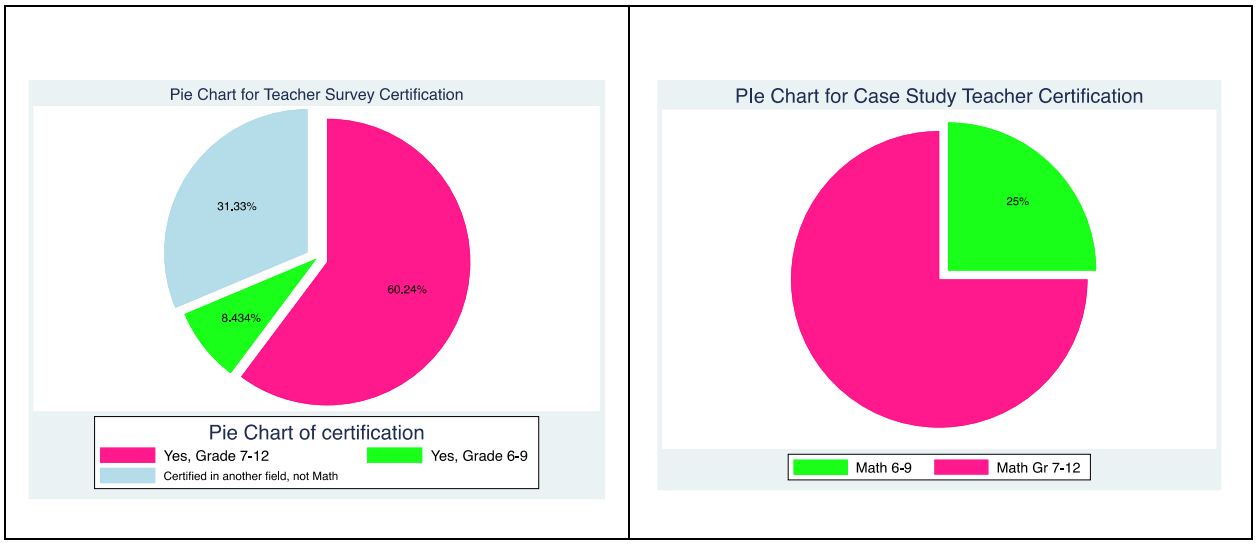



Figure 3.9 indicates that the majority (71% (59) of survey respondents) are White; 24% (20) are Black; 1% (1) are Asian; 3% (2) are Mixed) and 1% (1) are identified as Other. The high school teacher case study participants were predominantly (75%) White and 25% Asian.

**Figure 3.9.**

*Bar Chart of Teacher Race*

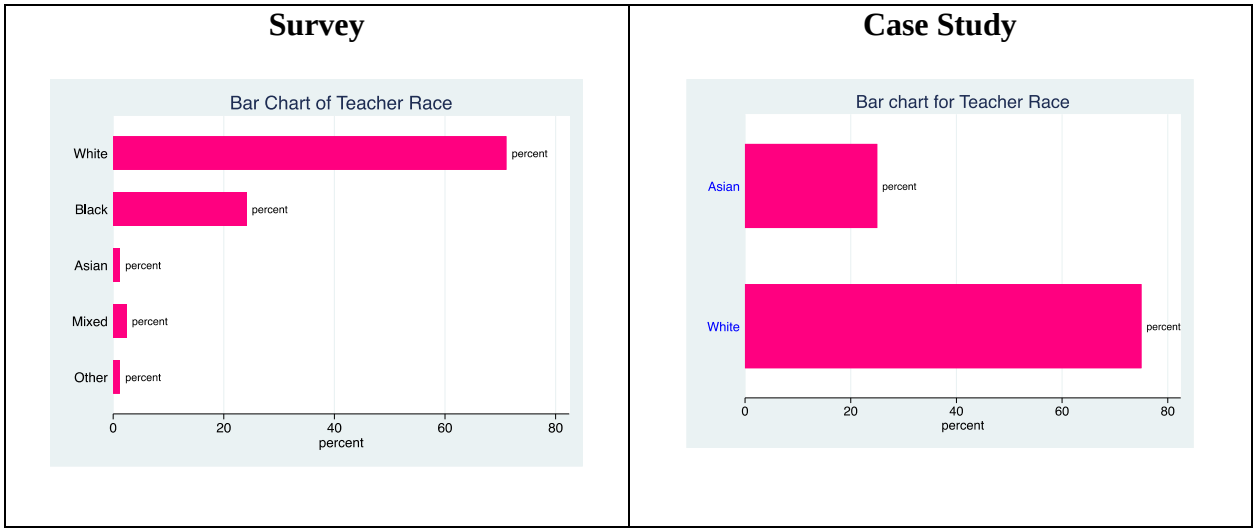
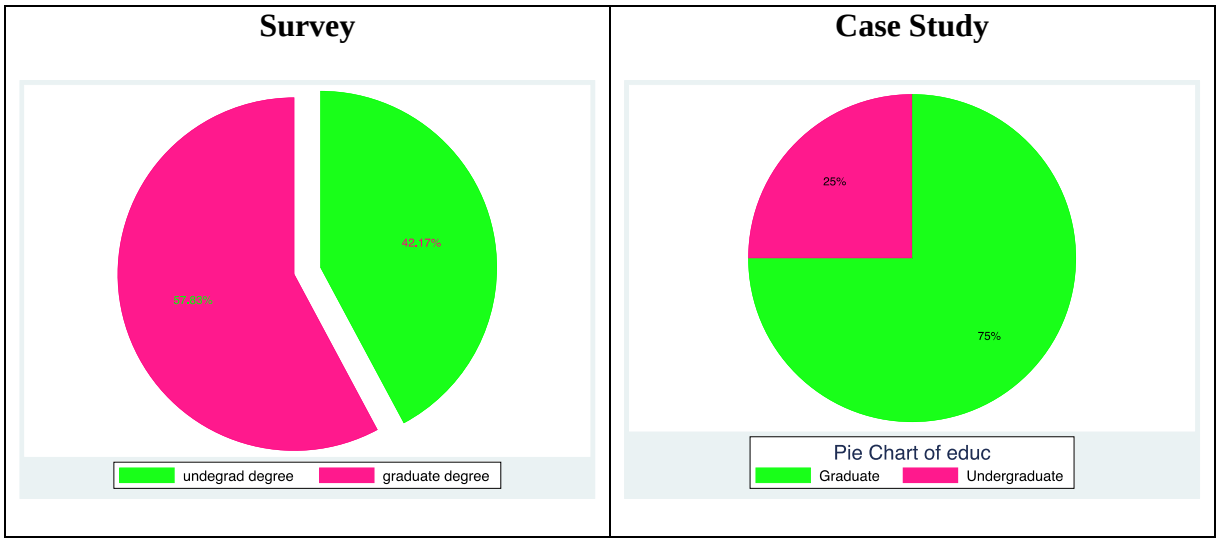


Figure 3.10 indicates that 42% (35) of the teacher survey respondents hold an undergraduate degree, and 58% (48) hold a graduate degree. For the case study teacher participants, 75% (3) hold a graduate degree, and 25% (1) hold an undergraduate degree.

**Figure 3.10.**

*Pie Chart Teacher Education Level*




***Data Analysis***

A joint data analysis was performed between the qualitative and quantitative findings to answer the alignment question. The qualitative data was transformed into quantitative (percentages/counts) for comparison. In addition, a joint display was created for an at-a-glance view of the quantitative representations (graphical and numerical summaries) and qualitative quotes from the interviews or observational data. This way, the alignment/congruence and misalignment/discrepancy between the data sets become apparent and observable.

This process allowed this researcher to examine and discern common or different patterns, helping in analyzing and forming conclusions about the story behind the data. Table 3.3 below is an example of the transformation of the interview and the class observation data into a

form that allows comparison between the two data sets. Table 3.4 is an example of quotes that allowed for the creation of Table 3.3.

**Table 3.3.**

*Transformation of Qualitative Data to Quantitative Data*

| | **Beliefs about Teaching with Technology** | | | **Self-Efficacy Beliefs** | | **Epistemic Beliefs** | | | | **Mode of Technology Use (Observation data)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dana** | T1 + | T2 + | T3 - | S1 mod con | S2 Not con | | E2 | E3 | E4 | M1 | M2 | M3 | M4 | M5 |
| **Jacob** | T1 + | T2 + | T3 - | S1 mod con | S2 Not con | E1 | | E3 | E4 | M1 | M2 | M3 | M4 | M5 |
| **Shiela** | T1 + | T2 + | T3 - | S1 mod con | S2 Not con | | E2 | E3 | | M1 r | M2 r | M3 | M4 r | |
| **Jona** | T1 + | T2 + | T3 - | S1 high con | S2 High con | | E2 | E3 | | M1 r | M2 | M3 | M4 | |

Note: "+" signs indicate "agreement," and "-" indicate disagreement. "R" reported but not observed.

**Table 3.4.**

*Example Teacher Quotes from Qualitative Data*

| Jacob Qoutes for M1 | Jacob Quotes M3 | Jacob Qoutes for M2 |
|---|---|---|
| So I think things like Desmos can change my instruction and they have like they've changed, they completely changed the way I teach transformations of functions like they've made it so much easier to make that like an exploration | students in conceptualizing the connection and that later on allow them to desctibe algebraic and graphical changes without the use of technology". | Desmos… completely changed the way I teach transformations of functions like they've made it so much easier to make that like an exploration, because before you either teach transformations or you make them graph it by inputting you know X values, calculate get the Y value, plot the point input X value. It just takes forever and ever and ever and ever and ever. And I think that like it's speed up my instruction of transformations of functions and kind of graphical representations in general..." (Follow-up Interview, October 12, 2023)<br><br>"I feel like I've done a better job of really utilizing some of the extra capabilities of like the TI-84, which I know is an old calculator, but I have the software now, so it's a lot easier to project onto the board what I'm doing and the kids can follow along and it's changed the way I assess … I asked questions to Algebra 2 last time about solving a system with a quadratic and linear equation and I felt like I was able to do that because…they had been instructed on how to graph it on a calculator and how to trace it and find their points." (Follow-up Interview, October 12, 2023) |

## Summary

In summary, this chapter discussed the study design and methods. This study employed a convergent mixed methods design, which includes two (2) strands. The quantitative strand examined the relationship between secondary in-service mathematics teachers' characteristics and beliefs (beliefs about teaching with technology, self-efficacy beliefs, and epistemological beliefs) and modes of technology use (MOTU) in the secondary mathematics classroom. The qualitative strand, a case study, was used to understand emerging themes and patterns from the data collected from the initial interview, semi-structured follow-up interview, and classroom observation.

To address the mixed methods question, the data collected from quantitative and qualitative strands were integrated to provide a finer-grained analysis not only of the relationship between the teacher characteristics and beliefs and mode of technology use (MOTU) but also to understand the nuances of the phenomenon of the mode of technology used in the secondary mathematics classroom in relation to teachers' characteristics and teachers' multidimensional beliefs, to determine the alignment beliefs and practice, to look at barriers to implementation and other pertinent occurrences useful for forwarding technology integration in mathematics teaching and learning.

The next chapter discusses the study findings, beginning with the quantitative (survey) findings and then the qualitative (case study) findings. The last section is the report on the joint analysis findings for the research's mixed methods aspect.

## Chapter 4 - Findings

This chapter discusses the findings of this study, beginning with the quantitative strand, followed by the qualitative strand, and finally, the findings of the joint analysis. The quantitative survey—findings discussion will be based on the research questions SubQ1: To what extent, strength, and direction are teacher characteristics associated with the mode of technology use? SubQ2: To what extent, strength, and direction are teachers' multi-dimensional beliefs about teaching with technology associated with the mode of technology use? SubQ3: To what extent, strength, and direction are teacher epistemological beliefs associated with the mode of technology use? SubQ4: To what extent, strength, and direction are self-efficacy beliefs associated with the mode of technology use? The summary of findings will answer the primary research question for this quantitative strand: "What teacher characteristics (gender, age, teaching experience, educational level) and multidimensional beliefs (b*eliefs about teaching with technology*, *self-efficacy beliefs, epistemic beliefs*) are associated with the mode of technology use in teaching math in the secondary classroom?"

The findings for the qualitative strand are discussed in the order of the research questions: SubQ5: How do teachers' characteristics and multi-dimensional beliefs translate into classroom practice (i.e., mode of technology use) in teaching and learning Math? And SQ6: What are the barriers to incorporating technology in teaching and learning Math?

The mixed methods findings will be discussed based on the joint data analysis, the survey's alignment/congruence and misalignment/discrepancies, and the case study findings.

## Quantitative Strand

The purpose of this section is to address the findings of the quantitative primary research question: What teacher characteristics (gender, age, teaching experience, educational level) and multidimensional beliefs (beliefs about teaching with technology, self-efficacy beliefs, epistemic beliefs) are associated with the mode of technology use in teaching math in the secondary classroom? The presentation of findings is in four sections based on the secondary research questions that focus on the relationship between 1) teacher characteristics and mode of technology use; 2) teacher beliefs about teaching with technology and mode of technology use; 3) teacher self-efficacy beliefs and mode of technology use, and 4) teacher epistemological beliefs and mode of technology use.

**Research SubQ1: To what extent, strength, and direction are teacher characteristics (age, gender, education level, experience) associated with the mode of technology use?**

Figure 4.1 reveals a symmetric distribution of teacher age, with the youngest 22 and the oldest 66 years old, with a center and spread (mean 39.5, SD=11). Meaning that, on average, teacher respondents were middle-aged. On the one hand, teaching experience shows a somewhat right-skewed distribution, indicating that most respondents have fewer than 20 years of teaching experience. The teaching experience reveals a minimum of 1 year up to 35 years of experience serving with a center ($\text{Mean} = 11;\ \text{SD} = 8$); the majority were in the service for 5 to 18 years.

**Figure 4.1.**

Graphical Displays and Numerical Summaries of Teacher Age and Experience

| Variables | Observations | Mean | StDev | Minimum | Maximum |
|---|---|---|---|---|---|
| Age | 83 | 39.59 | 10.604 | 22 | 66 |
| Experience | 83 | 11.313 | 8.042 | 1 | 35 |

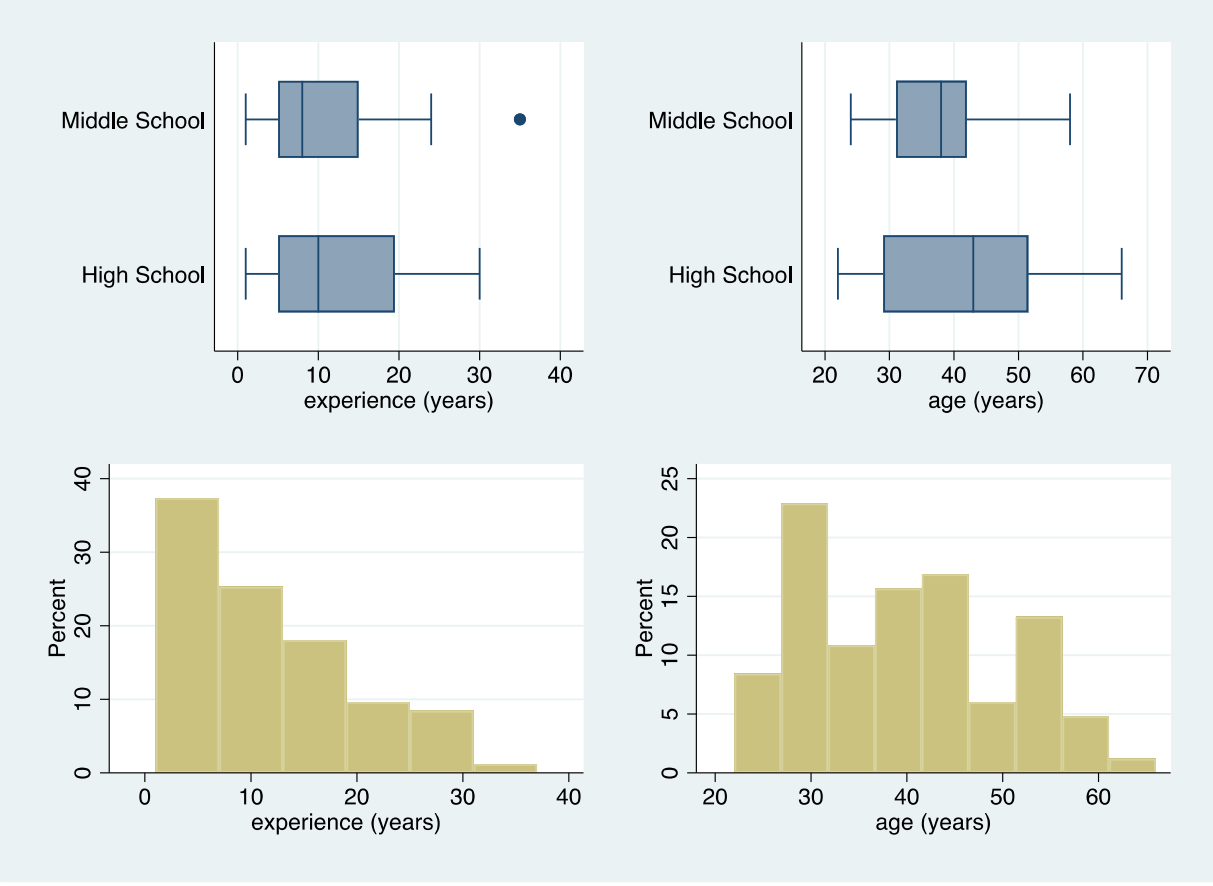



Figure 4.2 overall, teacher age has a statistically significant association with all modes of technology use. A particularly positive association exists between teacher age and technology use for discovery learning. However, there is a negative association with all other modes of

technology use. This result indicates that older teachers use technology more often for discovery learning and less frequently for multiple representation, practice, individual learning, and reflection.

A statistically significant association exists between teaching experience and the use of technology for discovery learning. It is negatively associated with multiple representations, which means that the more experienced the teacher, the more frequently they use technology for discovery learning but less for multiple representations.

**Figure 4.2.**

*Scatterplots and Correlations Teacher Age, Experience, and Mode of Technology Use*

| Variables | M1 | M2 | M3 | M4 | M5 |
|---|---|---|---|---|---|
| Age | 0.324* | -0.354* | -0.128* | -0.230* | -0.078* |
| Experience | 0.116* | -0.115* | 0.025 | -0.069 | -0.004 |

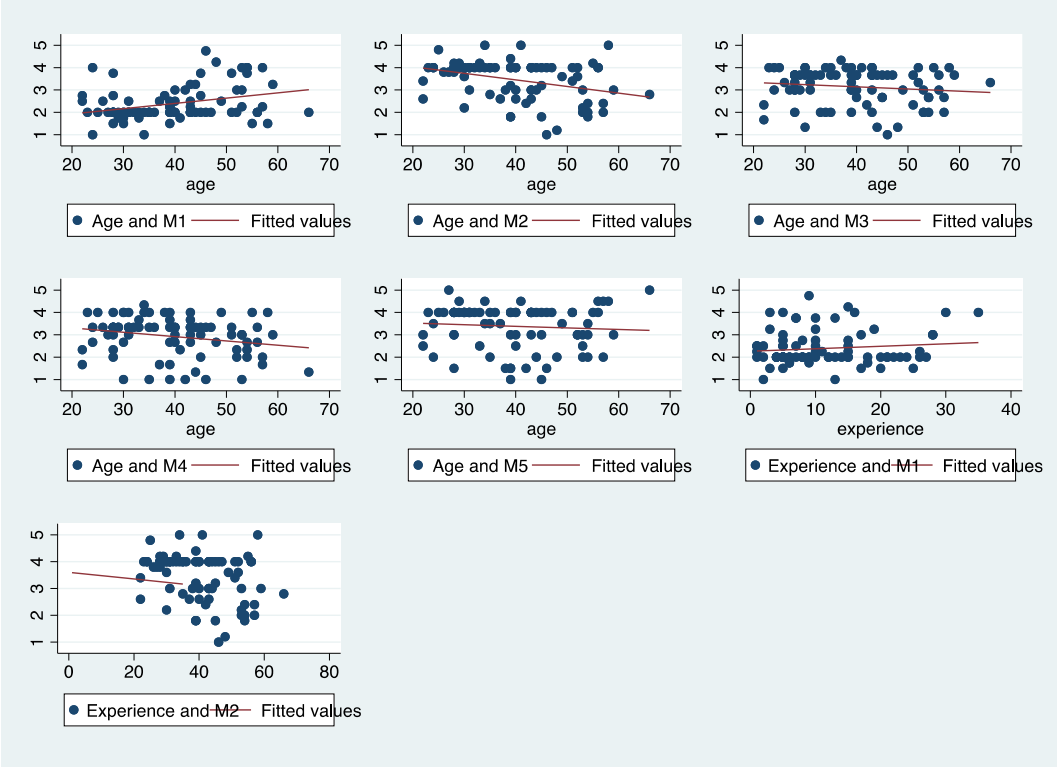


Table 4.3 reveals a statistically significant negative association between white teachers and the use of technology for discovery learning. However, a statistically significant positive association exists for multiple representations and practices. In addition, a statistically significant positive association exists between black teachers and the use of technology for discovery learning. While it is negatively associated with all the other constructs. In other words, black teachers tend to use technology more for discovery learning. There is a statistically significant positive association between Asian teachers and the use of technology for discovery learning but a statistically significant negative association with practice.

Mixed-race teachers of technology have a statistically significant but negative association with the use of technology for discovery learning and a statistically significant positive association for multiple representations, practice, individual learning, and reflection.
In other words, white and mixed teachers avoid using technology for discovery learning. In contrast, black and Asian teachers tend to use them more often; White teachers and mixed-race teachers tend to use technology more often for multiple representations compared to black and Asian teachers. Furthermore, both white and mixed teachers use technology more often for practice, while black and Asian teachers shy away. Only diverse teachers use technology more often for individual learning, and black teachers shy away from the use of technology for individual learning. Only mixed teachers use technology for reflection, while black teachers shy away from using technology this way.

**Table 4.1.**

*Pairwise Correlations Race and Mode of Technology Use*

| Variables | White | Black | Asian | Mixed | Others |
|---|---|---|---|---|---|
| **M1 Discover Learning** | -0.220* | 0.226* | 0.195* | -0.080* | -0.056 |
| **M2 Multiple Representation** | 0.094* | -0.150* | -0.008 | 0.096* | 0.068 |
| **M3 Practice** | 0.083* | -0.126* | -0.113* | 0.136* | 0.073 |
| **M4 Individual Learning** | 0.068 | -0.135* | 0.009 | 0.132* | 0.051 |
| **M5 Reflection** | 0.062 | -0.137* | 0.070 | 0.099* | 0.070 |

Table 4.1 shows that male and female teachers use technology inversely for individual learning and reflection. So, while there is a statistically significant positive association between male teachers and the use of technology or individual learning and thinking, female teachers' use of the same has a statistically significant negative association. It is worth noting, however, that the association is relatively weak.

**Table 4.2.**

*Scatterplots and Pairwise Correlations of Gender and MOTU*

| Variables | M1 | M2 | M3 | M4 | M5 |
|---|---|---|---|---|---|
| **Male** | **0.049** | **0.019** | **0.062** | **0.080*** | **0.141*** |
| **Female** | **-0.049** | **-0.019** | **-0.062** | **-0.080*** | **-0.141*** |

Table 4.3 reveals that undergraduate degree holders' use of technology is inversely related to graduate degree holders. A statistically significant association exists between teachers with undergraduate degree holders and technology use for discovery learning, multiple representation, practice, and reflection. While a positive association exists for multiple

representations, individual learning, and reflection, use for discovery learning is negatively associated. On the other hand, a statistically significant relationship exists between graduate degree holders for all modes of technology use except for individual learning. This means that graduate degree holders tend to use technology using discovery more often but less for other modes of technology use (i.e., multiple representation, practice, and reflection).

**Table 4.3.**

*Pairwise Correlations Education Level and Mode of Technology Use*

| **Variables** | **M1** | **M2** | **M3** | **M4** | **M5** |
|---|---|---|---|---|---|
| **Undergraduate** | -0.157* | 0.112* | 0.192* | -0.041 | 0.151* |
| **Graduate** | 0.157* | -0.112* | -0.192* | 0.041 | -0.151* |

Table 4.4. shows a statistically significant positive association between middle school teachers and the use of technology for multiple representation and individual learning but a statistically significant negative association for reflection. On the other hand, high school teachers show a statistically significant negative association with technology use for multiple representation and individual learning and a statistically significant positive association with the use of technology for reflection.

**Table 4.4.**

*Pairwise Correlations of Grade Level Taught and MOTU*

| Variables | M1 | M2 | M3 | M4 | M5 |
|---|---|---|---|---|---|
| **Middle School** | -0.038* | 0.117* | 0.049 | 0.181* | -0.151* |
| **High School** | 0.038* | -0.117* | -0.049 | -0.181* | 0.151* |

Table 4.5 shows that the mode of technology use for math-certified and non-certified teachers is inversely related and has a statistically significant weak negative association except for individual learning (M1). Teachers certified to teach high school math show a statistically significant negative association with using technology for reflection. Non-Math certified teachers have a statistically significant positive association with technology use for multiple representation, practice, and individual learning. However, a statistically significant negative association exists with using technology for reflection.

**Table 4.5.**

*Pairwise Correlations Teacher Certification and Mode of Technology Use*

| Variables | M1 | M2 | M3 | M4 | M5 |
|---|---|---|---|---|---|
| **Math Certified** | -0.028 | -0.130* | -0.095* | -0.164* | 0.188* |
| **Not Certified** | 0.028 | 0.130* | 0.095* | 0.164* | -0.188* |

Figure 4.6 reveals that teachers with undergraduate degrees have a statistically significant positive association with multiple representations, practice, and reflection but are negatively associated with using technology for discovery learning and individual learning. While graduate degree holders have a statistically significant positive association with the use of technology for discovery learning, it is negatively associated with multiple representations, practice, and reflection

**Figure 4.3.**

*Correlations Educational Attainment and MOTU*

| Variables | M1 | M2 | M3 | M4 | M5 |
|---|---|---|---|---|---|
| **Undergraduate** | -0.157* | 0.112* | 0.192* | -0.041 | 0.151* |
| **Graduate** | 0.157* | -0.112* | -0.192* | 0.041 | -0.151* |

**Research SubQ2: To what extent, strength, and direction does the teacher belief in teaching with technology associated with the mode of technology use?**

This research question pertains to the relationship between teacher beliefs about technology: supports discovery learning (T1), supports multiple representations (T2), high time requirement (T3), loss of by-hand calculation (T4), encourages mindless work (T5), requires prior mastery by hand (T6) and mode of technology use.

Figure 4.4 shows that the distribution of T1 and T2 are skewed to the higher values, indicating that about half of the teachers agree that technology supports discovery learning and multiple representations. The T1 and T2 boxplot reveal that more than 75% of the teachers believe that technology is beneficial to support student-centered or active learning and that technology is helpful in quickly changing between forms (i.e., graphical, symbolic, verbal, and numerical or tabular); and help students see connections and use different types of representations to solve problems or tasks.

**Figure 4.4.**

*Graphical Displays and Numerical Summaries: T1 and T2*

| Variables | Observations | Mean | StDev | Minimum | Maximum |
|---|---|---|---|---|---|
| **T1** | 83 | 4.036 | .771 | 1 | 5 |
| **T2** | 83 | 4.181 | .714 | 1 | 5 |

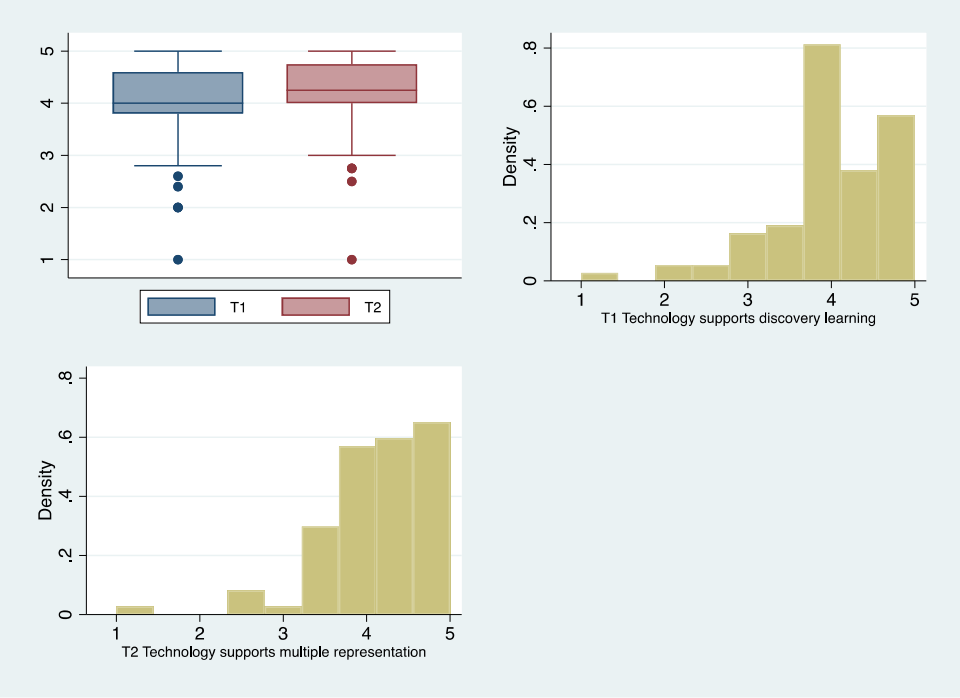
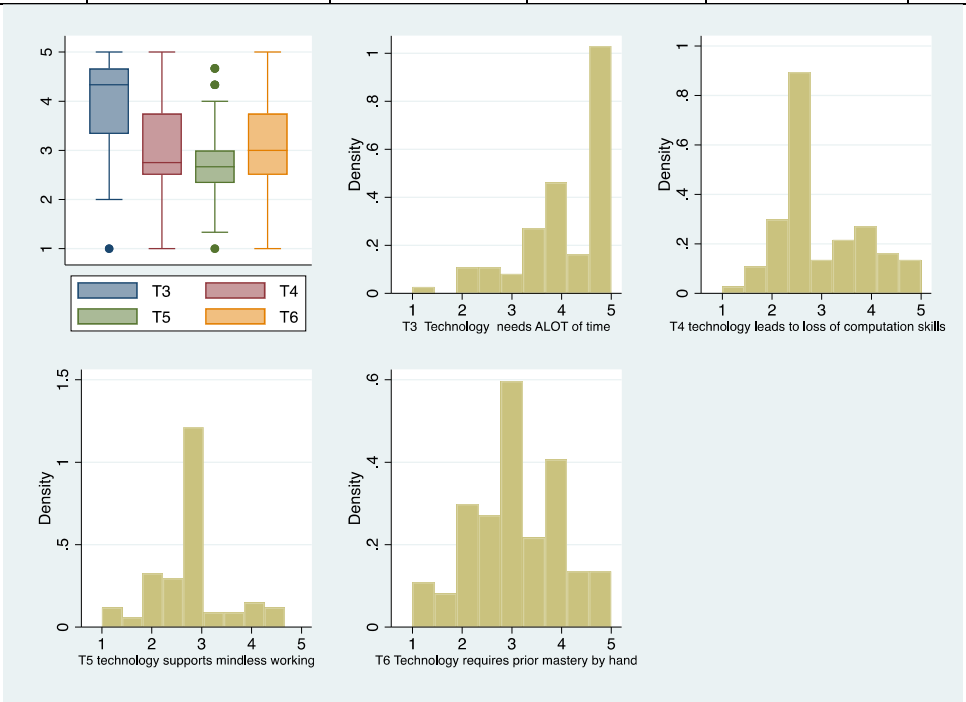



Figure 4.5 shows that the distribution of T3 is skewed to the lower values. The boxplot indicates that over 75% of teachers agree that technology requires too much time. On average, teachers think technology is worthwhile and will pay off in the long run. The distribution of T4 shows that more than 80% of the teachers disagree that technology results in students' loss of computation skills.

**Figure 4.5.**

*Graphical and Numerical Summaries of T3, T4. T5, and T6*

| Variables | Observations | Mean | StDev | Minimum | Maximum |
|---|---|---|---|---|---|
| **T3** | 83 | 4.036 | .865 | 1 | 5 |
| **T4** | 83 | 2.964 | .889 | 1 | 5 |
| **T5** | 83 | 2.703 | .729 | 1 | 4.667 |
| **T6** | 83 | 3.102 | .925 | 1 | 5 |




T5 distribution shows that the middle 50% of the teachers are tentative about the idea that math encourages mindless work. A few extreme believers are on each side of the spectrum, but most teachers report neutrality. Finally, the distribution of T6 shows a symmetric distribution, so about half of the teachers are neutral that mastery by hand is necessary before technology use. This finding indicates that, on average, teachers are tentative about whether students must have

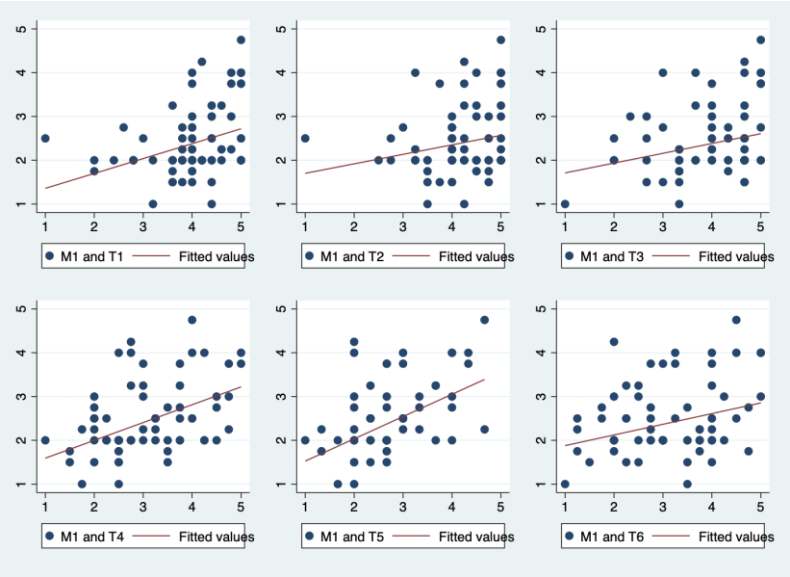
pen and paper mastery first or wait until they have sufficient understanding of mathematics before being given access to technology.

Figure 4.6 reveals that when teachers believe that T1 has a statistically significant positive association exists with M1. However, a statistically significant negative association exists for all other modes of technology use. Additionally, a statistically significant positive association exists between teachers' belief that technology supports multiple representations and the use of technology for discovery learning but is negatively related to all other constructs.

**Figure 4.6.**

*Correlation and Scatterplots of Beliefs about Teaching with Technology and MOTU*

| Variables | T1 | T2 | T3 | T4 | T5 | T6 |
|---|---|---|---|---|---|---|
| M1 | 0.340* | 0.201* | 0.251* | 0.468* | 0.480* | 0.292* |
| M2 | -0.193* | -0.147 | -0.179* | -0.372* | -0.462* | -0.112* |
| M3 | -0.151* | -0.214* | -0.190* | -0.401* | -0.397* | -0.125* |
| M4 | -0.155* | -0.283* | -0.002 | -0.242* | -0.479* | -0.106* |
| M5 | -0.237* | -0.136* | -0.038 | -0.344* | -0.345* | -0.166* |



**Research SubQ3: To what extent, strength, and direction are teacher epistemological beliefs associated with the Mode of Technology Use?**

This research question pertains to the relationship between teacher self-efficacy beliefs (S1), selecting and designing tasks (S2), designing, and implementing lessons that include technology with modes of technology use.

Figure 4.7 reveals the skewed distribution of both S1 and S2 to the higher values. Both the boxplots show that about half (50%) of the teachers are confident in their ability to (S1) select and design tasks as well as (S2) design and implement lessons using technology that support discovery learning, clarify relationships, and explore the graphical potential of technology use in the classroom; In comparison, about 25% neither agree nor disagree.

**Figure 4.7.**

*Graphical Displays: Teacher Self-Efficacy Beliefs*

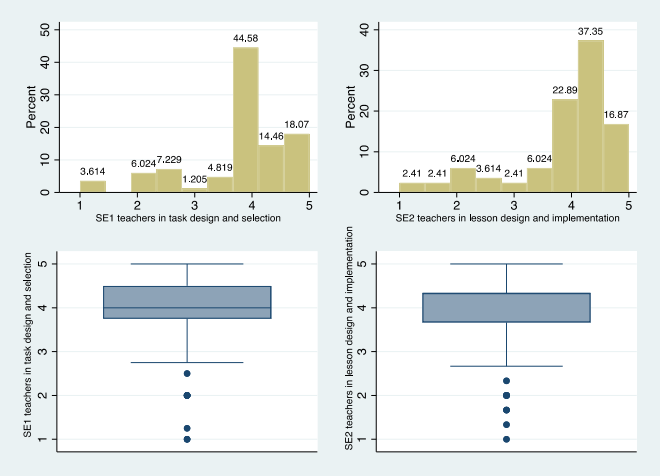


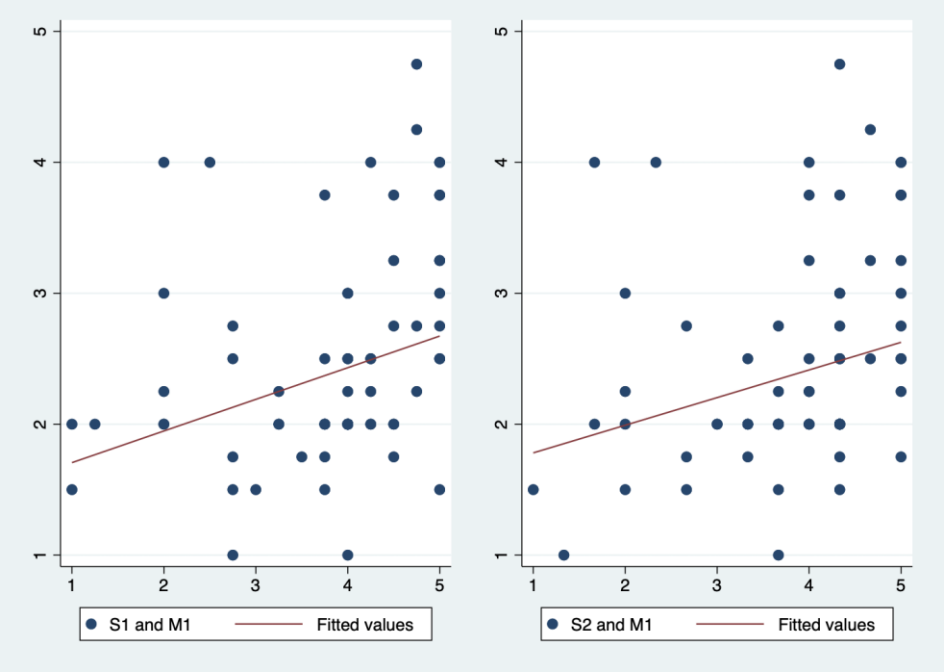

Figure 4.8 reveals that both teachers' self-efficacy beliefs in selecting and designing tasks with technology (S1) and teachers' self-efficacy beliefs in their ability to design and implement a lesson (S2) have a statistically significant positive association with the use of technology for

discovery learning (M1). All the other modes of technology use were statistically significant but had a negative association.

**Figure 4.8.**

*Scatterplots and Pairwise Correlations: Self-Efficacy Beliefs and MOTU*

| Variables | S1<br>Task Design and Selection | S2<br>Lesson Design and Implementation |
|---|---|---|
| **M1 Discover Learning** | 0.293* | 0.255* |
| **M2 Multiple Representation** | -0.294* | -0.216* |
| **M3 Practice** | -0.270* | -0.151* |
| **M4 Individual Learning** | -0.097* | -0.016 |
| **M5 Reflection** | -0.228* | -0.155* |



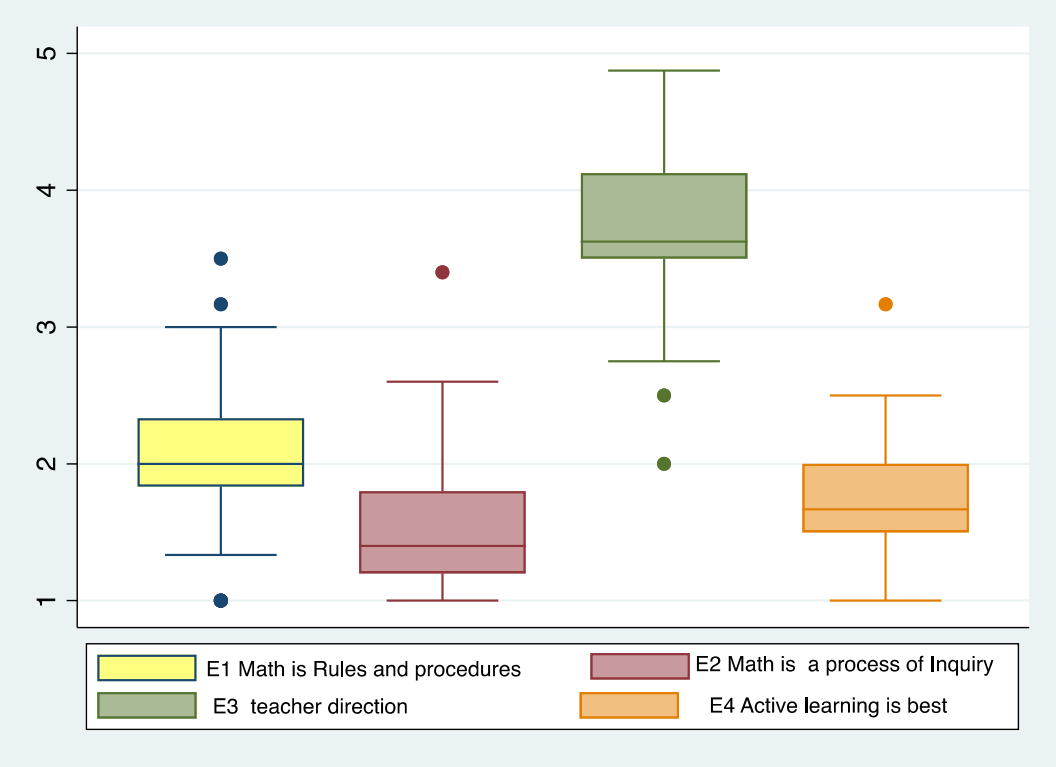

**Research SubQ4: To what extent, strength, and direction are epistemic beliefs associated with Mode of Technology Use?**

Figure 4.9 reveals skewed distributions for teacher epistemic beliefs. E1, E2, and E4 distributions have similar centers (median approximately two or less), while E3 has a higher

center (median of about 3.5). The box plots of E1 and E2 both indicate that skewed to the higher values indicating that majority, more than 95%, of the teachers disagree that math is either just a process or a set of rules and procedures. This means that teachers may hold eclectic belief about the nature of mathematics. The box plot skewed to the higher value for (E3) indicates that more than 95% of teachers agree that math is best learned through teacher direction (E3). The opposite is true with (E4).

**Figure 4.9.**

*BoxPlots of Teacher Epistemic Beliefs*




Tables 4.6 and 4.10 reveal a statistically significant positive association between the teachers' belief that math is, by nature, a set of rules and procedures and the use of technology for practice (M3); a statistically significant but negative association between the use of technology for discovery learning (M1) and individual learning (M4).

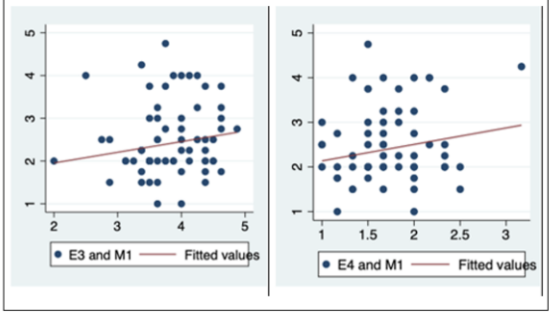
When teachers believe that, by nature, math is inquiry (E2), there exists a statistically significant positive association for multiple representations (M2), individual learning (M4), and reflection (M5) but negatively associated with the use of technology for discovery learning (M1) and practice (M3). A statistically significant positive association exists between the teacher's belief that learning math is best with (E3) teacher direction and the use of technology for discovery learning (M1). This finding means that even if teachers believe they are the best source of knowledge, they tend to use technology for discovery learning. However, it is negatively associated with all the other constructs.

A statistically significant positive association exists between technology for discovery learning and the best way to learn mathematics using (E3) teacher direction and (E4) active inquiry. This means that teachers who believe that math is learned best via teacher direction (E3), or student-centered (E4) activities tend to use technology for discovery learning (M1). However, a statistically significant negative association exists between the belief that math is a process of inquiry (E2) and other constructs like multiple representations (M2) and practice (M3).

**Figure 4.10.**

*Correlations and Scatterplots Epistemic Beliefs and MOTU*

| Variables | E1 Rules & Procedures | E2 Inquiry | E3 Teacher Direction | E4 Active Inquiry |
|---|---|---|---|---|
| M1 Discovery Learning | -0.127* | -0.097* | 0.167* | 0.191* |
| M2 Multiple Representation | 0.006 | 0.112* | -0.200* | -0.126* |
| M3 Practice | 0.156* | -0.108* | -0.120* | -0.108* |
| M4 Individual Learning | -0.144* | 0.158* | -0.293* | 0.059 |
| M5 Reflection | -0.003 | 0.094* | -0.084* | -0.034 |



## Summary

### *Teacher Characteristics and Mode of Technology Use*

Figure 4.11 shows that teacher characteristics do not play a pivotal role in teacher practice (i.e., mode of technology use). However, specific teacher characteristics, such as age, experience, nonwhite, and a graduate degree, show statistically significant positive associations with using technology for discovery learning.

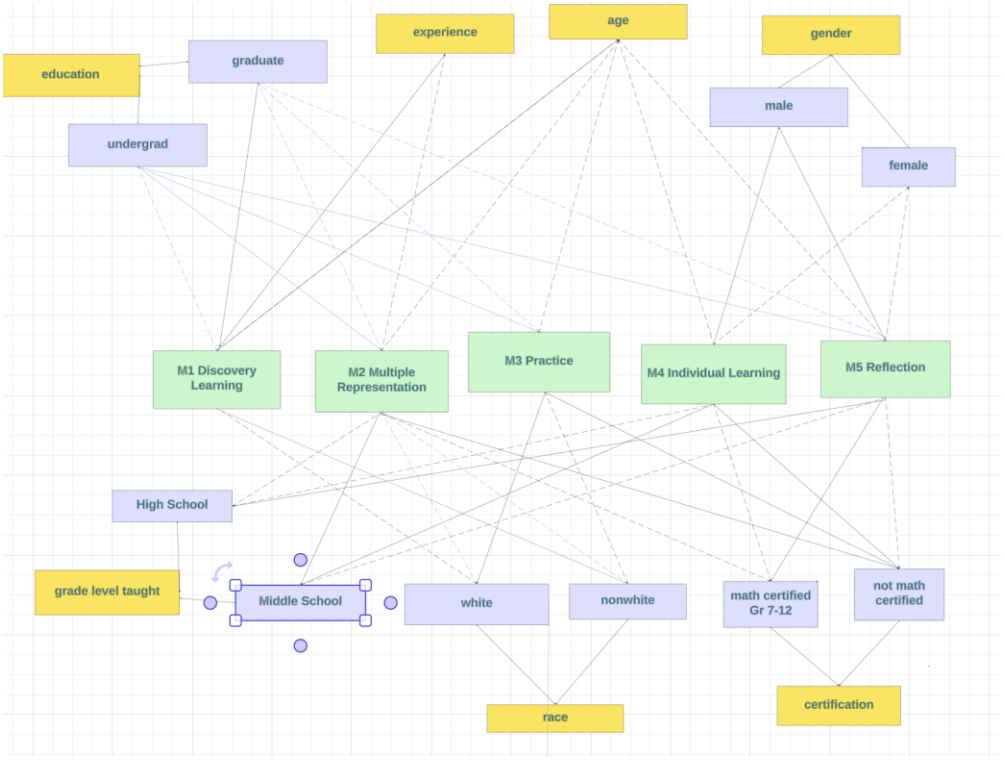
In addition, teacher age, undergraduate degree, and certification have a statistically significant positive relationship with using technology for multiple representations.

Being white, holding an undergraduate degree, and being nonMath certified have statistically significant positive associations with using technology for practice.

Male, middle school, and non-math-certified teachers reveal a statistically significant positive association with using technology for individual learning. While being a high school teacher, math certified for Gr 7-12, male, and longer teaching experience shows a statistically significant positive association for using technology for reflection.

**Figure 4.11.**

*Diagram of the Relationship Between Teacher Characteristics and MOTU*




Note: The solid lines connecting the dependent variables (MOTU) indicate a statistically significant positive association with each teacher's characteristics at a 0.1 alpha significance level. The broken lines indicate a statistically significant negative association.

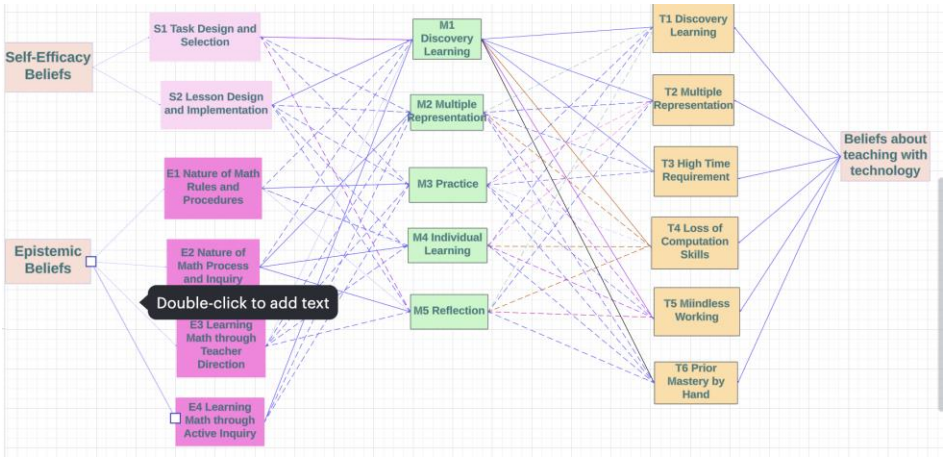
*Teacher Beliefs and Mode of Technology Use*

Figure 4.12. below shows that overall, no matter what belief teachers hold about teaching with technology, the preponderance of evidence suggests that teachers' reported use of technology generally points to discovery learning. It is especially notable for cases where teachers believe that technology is perceived to be a barrier, such as the belief that technology results in loss of computation skills (T4), that technology requires too much time (T3), or that technology encourages mindless working, teachers still reported a statistically significant positive association indicating that their use technology more frequently for discovery learning (M1). The same is true with self-efficacy beliefs, which have a statistically significant positive association with using technology for discovery learning (M1). A statistically significant

positive association among epistemic beliefs reveals that when teachers believe math learning is best via teacher direction and active inquiry. Both the beliefs about teaching with technology and self-efficacy beliefs are instrumental to using technology for discovery learning or constructivist teaching practices. The mode of technology for discovery learning or constructivist approaches is a primary trend in Mathematics teaching practice.

**Figure 4.12.**

*Diagram of Relationships Between Teacher Beliefs and MOTU*




Note: The solid lines connecting the dependent variables (MOTU) indicate a statistically significant positive association with each teacher's sub-dimensional beliefs at 0.1 alpha significance level; The broken lines indicate a statistically significant negative association

**Qualitative Strand**

This section reports on the case study findings based on the four teacher participants from the same high school to elucidate the findings of the two research questions for the qualitative strand of this study. This discusses the uncovered hidden themes from the data collected (initial interviews, follow-up interviews, and classroom observations that included pre- and post-observation questions). The sequence of discussion in the order of the two qualitative research questions posted is as follows:

**Research Question 5: How do teachers' characteristics and beliefs translate into classroom practice (i.e., mode of technology use) in teaching and learning Math?**

***Theme 1: Teachers' self-efficacy beliefs about technology align with their classroom practice.*** Teachers' self-confidence is directly linked to their practice of using technology in teaching and learning math. There is an indication that their initial personal experiences inform their mode of technology use so as the frequency of use. So, when teachers experience success with technology use in their initial try, they are more likely to use it again. The taste of successful practice then allows their self-confidence to grow with time. In his initial interview, Jacob mentioned that "the first time was always iffy, and the next time was always better. "He also said, "The more experience I've gotten, the easier it's become." His self-confidence in using technology has grown so much that he challenged his students by posing questions that he thought students would have needed the affordances of technology to figure out.

> I asked questions Algebra 2 [students] last time about solving a system with a quadratic and linear equation, and … I was able to do that because if they couldn't do it algebraically, they had been instructed on how to graph it on a calculator and how to trace it and find their points. I feel like I've done a better job of really utilizing some of

> the extra capabilities of, like, the TI-84, which I know is an old calculator, but I have the software now, so it's a lot easier to project onto the board what I'm doing, and the kids can follow along, and it's changed the way I assess. (Jacob, Follow-up Interview)

Like Jacob, Dana also pointed out that her self-confidence in using technology in the classroom grows more with personal successful experience and time. In addition, her confidence was affected by the student's perception of the learning experience. On the one hand, Sheila had some initial experiences using technology while teaching her Precalculus class. The students did not like their experience, so Sheila never used the technology in her class in that way again. Sheila indicated in her pre-observation responses that she used technology sporadically (once or twice a week), usually to help review concepts from a previous lesson.

***Theme 2: Teachers' beliefs about how math should be taught may direct their adoption of technology in the classroom***

**Subtheme 1: Teacher-centered instructors used technology as an instructional supplement.** Sheila and Jona tended to conduct teacher-centered practices, seemingly supporting the belief that learning math is best with teacher direction. During classroom observation, for example, Sheila held direct instruction where she was at the center of the classroom, explicitly providing instructions on what to write on the student's notes (foldable). Sheila demonstrated to students how to work out problems, including the sequence of entering numerical expressions in the calculator to find what they were looking for. She then gave students similar examples to practice, gave them time to work independently, and showed them the correct answers and how to find them after some time.

Sheila did use technology (Desmos) at the beginning of class to review and practice skills from the last lesson. The technology was self-checking, so students knew if they were getting it

right. Like Sheila, Jona also conducted direct instruction on the task for the day with a little twist since the day of the observation was also an assessment day with direct instruction at the beginning. She started the class by reviewing the tasks of the day and reading the expectations of the course; she demonstrated to the class the use of Microsoft Excel to calculate numerical summaries (i.e., mean, median, standard deviation, 5-number summaries) and construct graphical displays (i.e., histograms, boxplots, etc.). After the demonstration, she instructed students to develop a topic to investigate and then reach out to her for topic approval before proceeding with data collection, calculating numerical summaries, and constructing visual displays. After topic approval, students were to use the internet to collect the data, use Excel to analyze them, put the data on a graphic organizer, and then use either presentation software or a poster paper in preparation for presentation or grading.

In her initial interview, Sheila indicated, "Technology should be used to supplement the activities and things that are already going on in your class." She shared that “technology (they) shouldn’t be used to replace things already working well." Sheila indicated that technology only changes her practice more for the time it takes to grade students' work.

**Subtheme 2: Student-centered instructors use technology to facilitate learning.** Although Jacob initially reported teacher-directed tendencies, he and Dana were both observed to use student-centered practices, indicating their belief of how math is learned best may be more dialectic. Both teachers used technology during the classroom observation days to deliver the lesson to the students. Both teachers were walking around providing help to those students who were stuck. The technology-delivered activity unfolds the concept as the students work on the slides. After a while, both teachers reviewed specific slides to clarify some ideas students may need help understanding based on their responses. Dana introduced the Algebra 2 class to the

concept of exponential functions. The activity started with pattern recognition that included a what do you notice, what do you wonder slide.

In his initial interview, Jacob mentioned that technology helps "students conceptualize the connection and eventually describe algebraic and graphical changes without the use of the technology." Dana, in her pre-observation and initial interview responses, expressed that technology use allows students to "explore like plug in something and then see what happens", “helps in deepening understanding and providing more applications of concepts," allows students to “work interactively when doing exploratory work," allow for “enrichment lessons,” and efficiently “assess students learning and give student feedback faster.”

***Theme 3: If teachers believe technology fosters positive teaching practices, they are more likely to adopt***

**Sub Theme 1: General benefits to teaching practice.** Teachers found that technology affordances included more teacher freedom, saving time, grading student work, holding students accountable, reviewing students’ prior knowledge, helping with classroom management, helping build student confidence, and accounting for student learning needs and preferences.

For example, in her initial interview, Jona expressed her appreciation of technology because it frees her up to help struggling students. This freedom means a lot to her because she can work with “a small pockets of students, to make sure that they understand." Also, technology (Matthia) “break people into groups, that allow students to work on the same workspace.” (Jona, Follow-up Interview) Technology helped with classroom management practices because “it minimizes distractions, minimizes behavior issues."(Jona, Follow-up Interview)

Technology also allows for innovative lesson planning, such as the lesson used for Jona's classroom observation, constructed by ChatGPT, a web-based AI capable of explaining a concept and creating a lesson plan. Jona explained that

> ChatGPT could … help with lesson planning...[if] I don't want to do the traditional classroom, but I want to use these materials. You could say, hey, can you turn this lesson into an interactive assignment? Check what it comes up with. Then maybe it comes up with some ways to make the kids interact with each other. (Jona, Follow-up Interview)

During one of the classroom observations in her Algebra 1 class, Jona's students were asked to describe and compare the shape, center, and spread of two or more data distributions of a single variable. The teacher gave instructions about the task and "explained that the students can use the computer because the target is to interpret the data and not to calculate the number summaries." She also mentioned how one of her students shared a screenshot of the graphical displays of her work on a paper graphic organizer and CANVA, an online presentation tool, showing the usefulness of technology in making learning visible, shareable, and easily accessible to all.

In her initial interview, Dana mentioned that technology helped make instruction easier and faster, allowed students to review big ideas, and gave students feedback more quickly. Also, Dana figured that because of the technology's (Demos) embedded functionality, student learning was even more engaging as students were allowed to express their understanding and thinking process and ultimately were allowed to share with the whole class. (Dana, Classroom Observation) Furthermore, Dana said that the use of the (Desmos) activity shortened the downtime and made work interactive when doing exploratory work" (Dana, Classroom Observation). It was also beneficial for diverse learners, linguistic or otherwise, were

"If the student is in ESL, then you allow them to use a translator, and then I have kids who need headphones so they can focus more. So, some kids are working better with Deltamath than the paper and pen practice." (Dana, Follow-Up Interview)

Sheila mentioned using technology (Desmos) to hold her students accountable and activate prior knowledge. The graphing calculator (TI-84) helped her students who are more visual people (Sheila, Initial Interview). She also found that technology "helps with confidence building."

Jacob shared that technology use allowed him to change his instruction for more student engagement and saved up on time. In his follow-up interview, he shared, "It speeds up my instruction of transformation of functions and kind of graphical representations in general." He also noted that technology allows "students access to a more interactive" experience and that he can pose "…open-ended and probing questions to all students and responses were shared to the rest of the class." (Follow-up Interview) There are times "…that students were allowed to express their findings in their own words and shared to the whole class via the technology" (Jacob, Follow-up Interview)

**Subtheme 2: Discovery learning** Teachers found that technology can be an excellent tool for students to discover mathematical concepts that are otherwise abstract, cumbersome, and unfamiliar. For example, during the classroom observations, Dana and Jacob were both teaching Exponential Functions in their Algebra 2 class. Dana used Desmos to introduce exponential functions starting with geometric sequences, a review from Algebra 1. The Desmos activity led the students to discover the formula for the exponential function, including growth and decay. The lesson posed leading questions such as "What do you notice and wonder?" and then they were asked to write their observations" which were then shared with the class (Dana, Classroom

Observation). When necessary, she would also encourage her students to use technology to visualize functions and "explore like plug in something and then see what happens." (Dana, Follow-up Interview)

Jacob used technology in a way that "activities with these tools help students conceptualize the connection and eventually describe algebraic and graphical changes without using the technology" (Jacob, Initial Interview). For example, during classroom observation, the students used technology (Desmos) to discover an exponential function's graph and its transformation. While Jacob gave students a document with a summary of the lesson as a preview, they could explore how the points that satisfy the exponential function look graphically. For him, "discovery can be a great way for students to buy into math," and "technology helps students make connections" (Jacob, Follow-up Interview) without students getting bogged down by cumbersome calculations due to a lack of calculation skills.

During her follow-up interview, Sheila recalled how "Agile mind (a mathematical software… have, like the demonstrations of like cutting. Cutting a circle and it like pulled it, open it up and like and gives you the area." She remembered how the technology called AgileMind "helped me understand it (circles) better." Jonah also encouraged her students to "explore with Desmos-find the reasons [why] the math works."

**Sub Theme 3: Multiple Representation** Teachers found that technology use made viewing mathematical concepts in different forms (i.e., graphical, tabular, or numerical, symbolic, or verbal) accessible for all students. Jacob, in his initial interview, figured that "Desmos and graphing calculators are things I use to support developing connections between" because, he added, "activities with these tools help students conceptualize the connection and eventually describe algebraic and graphical changes without the use of the technology." He also thought

that you could "…graph multiple equations on one plane and then use that trace function just to identify points of intersection." (Jacob, Follow-Up Interview)

In her follow-up interview, Jona expressed that a technology called "Matthia will take them [the students] through different models of the same type of problem, so they learn multiple ways." During classroom observation, Dana used technology to "encourage the students to use multiple representations to demonstrate their thinking." For example, slides required students to write three terms after the first two terms. Some slides asked students to write an explicit formula and an exponential function form for a given geometric sequence given the first five terms. Slides included a sequence of numbers, a table, charts, or graphs showing how geometric lines, their explicit formula, and exponential function form." (Dana, Classroom Observation) "When students understand how to write the explicit formula for a geometric sequence, they will be able to connect it to exponential function and will understand conceptually what the letters in the functional form mean." (Dana, Classroom Observation). Sheila also said, "Desmos is one that I will use in my Precalculus class quite a bit when we are looking at the graphs of different functions." (Sheila, Initial Interview) indicating that she uses technology for multiple representations.

**Subtheme 4: Practice or Do math** (i.e., tool for manual or replacement for mental calculation)

High school Math teachers are finding that for high school students who have academic gaps, including mental calculation skills, technology has been a valuable ally for students in doing the math. This is not only for "problems that are … too large or cumbersome to complete by hand" (Jacob, Initial Interview) but also for fundamental enumeration problems. In fact, during the classroom observation, Sheila was witnessed, knowing her Geometry students so well, showing exactly how to enter expressions on their calculators to find what they are looking for. In

addition, Jona thought that the technology called Deltamath's capability to self-check helps reassure the students that the math works. (Jona, Initial Interview)

**Sub Theme 5: Individual learning**

Teachers found that technologies are beneficial for self-paced learning and great for catching up on lessons when students were gone from school for one reason or another. Teachers often need to be more concerned about students missing important math lessons in a transient population like the participants' school. Hence, technology affordance that catches students up but does not necessarily have teachers repeat themselves is infinite because technology can do most of the teaching and is highly valued. With technology, teachers come in to clarify or strengthen based on student needs.

For example, during her follow-up interview, Jona said, "Deltamath is better because of the videos. It's perfect for when kids are absent, and you need someone to explain the math and see some problems, but that's if you want to mentor the algorithm." In addition, Jona mentioned that if the teacher ran out of time, students could continue with the lesson: "… if you don't get through the lesson, go ahead, and get them on. Mathia will teach them the lesson." She added, "It's perfect for when kids are absent, and you need someone to explain the math and see some of the problems, but that's if you want to mentor the algorithm.

Sheila mentioned liking technology in her pre-observation because it allowed "Students to work at their own pace and get through as much material as they can do, while those that can finish the whole Desmos activity." To her, practicing multiple items for each type of problem was a priority. She would tell her students, "I want you to do this many problems of adding and subtracting or this many problems of simplifying radicals or whatever."

During the classroom observation, Dana used technology that allowed "the students were observed to work independently on slides. "The observation lesson was intended, and successfully implemented, to be "individualized in a way that students' prior knowledge allowed them to progress faster and on their own with the help from the teacher here and there."

**Research Question 6: What are the barriers to incorporating technology in teaching and learning Math?**

***Theme 1: Barriers internal to the teacher*** inhibit teachers from integrating technology into their teaching practice. These factors were discomfort, the lack of training from teacher preparation courses, and the need for math-specific technology courses.

Jacob and Sheila confessed to this feeling of discomfort in their practice. For instance, Sheila admitted that she didn't know how to use the intelligence board until she was in a classroom as a student teacher. She admitted to never having a class on technology. Her discomfort ended up limiting her use of, say, Desmos because for an activity where she had to

> change the coding, it will be a no … She felt very uncomfortable, especially when she said, I've tried the coding aspect. I'm not as good on that part, so maybe a three (somewhat comfortable). "Like something from scratch, I haven't done, and that's why I said I'm not that comfortable; I would love to do … not a coding class, but a Desmos coding.

Jacob admitted that lack of training during the teacher preparation program inhibited him from making the most of the technology available. He thought that a

> separate class[es] like technology in the mathematics classroom …would have been more helpful. "We need a class over Desmos, and I don't know if Delta math existed … but Desmos, Delta[math], Quizziz… all those things we use in our math room regularly. "

So, I feel like it would have been helpful. I don't know if it would be possible, but it would have been beneficial if there was like a program for math teachers on like. This is how the TI software looks, or this is, you know, the math-specific things because there was like there was a technology in education class which was useful, but it was also really generic like all the math, or all of the education majors took it like elementary through high school no matter what. (Jacob, Follow-up Interview). In support of Jacobs's thoughts, Dana also felt the need for "…a lot of training, and …more time to practice."

***Theme 2: Barriers external to the teacher*** Teachers mentioned inhibiting factors for maximum use of technology affordances in the classroom are those considered **beyond their control**, including the need for free access to just-in-time appropriate resources, limited appropriate technology access, time, cost to access technology, and user-friendliness.

All four participants discussed their **monetary concerns** about accessing and using appropriate technologies in their initial and follow-up interviews. For example, Sheila talked about hardware access and software subscriptions that are "costly for the students to have this equipment and for the teacher to buy some of the subscriptions." Dana mentioned that the "accessibility and efficiency of computer devices, availability of software, or teacher-friendly resources" were expensive. She also talked about the need for affordance just-in-time resources that are appropriate for her students' markets that have features like:

"Deltamath, they are already being premade, so all I gotta do is just add them … into my assignment. And then, on Desmos, I normally search for what other people have done and edit them. I have probably made one, but I just patterned it to a previous [one that was] already created." (Dana, Follow-up Interview)

Sheila and Jacob shared an additional concern about time being a resource. Sheila indirectly mentioned time as a constraint.

> If I have something new that I want to do, I'm going to try [the] technology. Because then I don't have to create it. I don't have to cut it out. I don't have to do anything like that, so for me, it's a case of ... convenience, really (Sheila, Follow-up Interview).

In the essence of time, Sheila wished that technology "provide feedback for every question in real-time." She needed access to technology that had an infinite set of question items where she could pick and choose. She said, "I like the ones where I can pull a question from this pool of questions and make my own, umm, Quizziz."

And to add more to the time issues, Jacob mentioned the recent district initiative.

> "like in this district in the last couple years, one of the choices on you know, those choice days, someone presented on Desmos activity builder, and I think a lot of people went like it was really popular, but it's not, that was just one of those things where like the district asked, hey, do you have something to present and somebody was like I could present on Desmos, but it was a hit because **nobody has the time to go figure it out by themselves,** but they would be willing to bring their laptop to an in service and follow along while someone shows them the basics, …on our next choice session … will somebody show me how to use Deltamath please like give me something to use."

There was also an indication that teachers found some technology rather tricky or not helpful, causing them to refrain from using it. Jacob thought, "Some technology is not very easy to use, which is sometimes a reason not to use that tool." Sheila talked about the need in mathematics to show the process, such as "writing things down and showing their steps and work." This can be done on the computer but can be complicated for students." Jona also

mentioned that technology for teaching can be limited, indicating that current technologies are still a work in progress. In her words, she said

> The technology teaching is only as good as the program. Some programs are better than others (i.e., proofs on Deltamath are too long [should be shorter]). I cannot use every lesson on Deltamath because some assignments confuse students. Technology shows the kids what they know before testing so they already know when it is time to prove they learned" (Follow-up Interview)

**Mixed Methods: Joint Display Analysis and Findings**

This section will discuss the findings in alignment/congruence or misalignment/discrepancy between the quantitative and qualitative findings. The discussion begins with the relationship or role of teacher characteristics and the multidimensional beliefs (teaching with technology, self-efficacy, epistemological beliefs) on teaching practice (i.e., mode of technology use in the mathematics classroom).

***Teacher Characteristics and Mode of Technology Use***

Figure 4.13 shows that the survey teacher age and technology use for discovery learning (M1) has a statistically significant positive association (r=0.324*, moderate), indicating that older teachers use technology more frequently. Meanwhile, the case study shows that teachers' age is inversely associated with the frequency of technology use for discovery learning. This means older teachers use technology for (M1) discovery learning less frequently than younger teachers.

**Figure 4.13.**

*Scatterplots of Teacher Age and Mode of Technology Use*

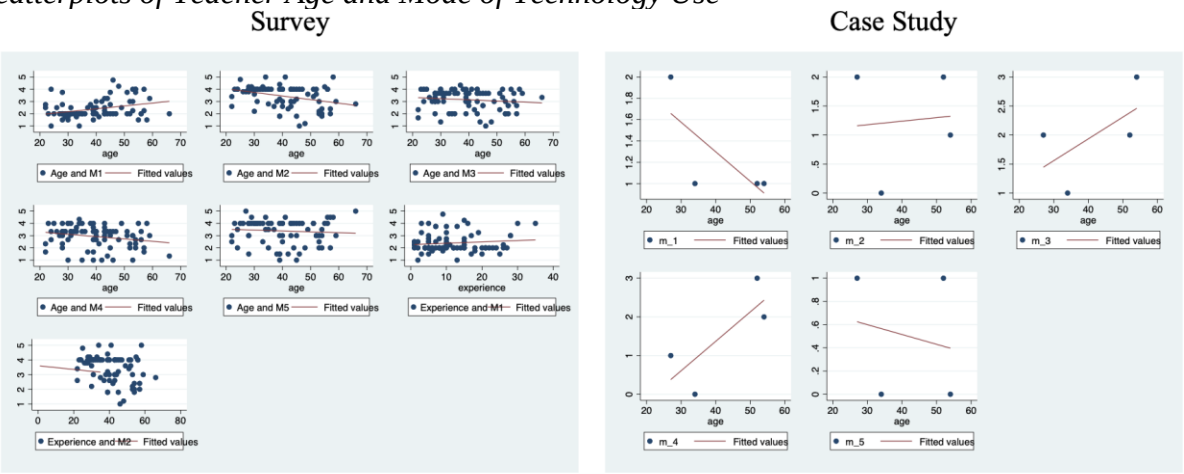


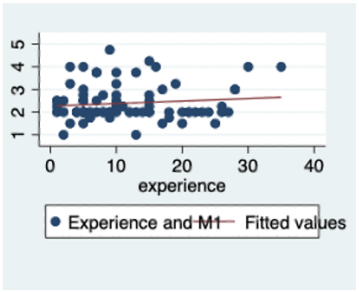

Figure 4.14 shows survey findings indicating that more experienced teachers frequently use technology for (M1) discovery learning ($r = 0.116*$), while the case study teachers show no difference. This discrepancy is unsurprising because the case study has a significantly smaller sample.

**Figure 4.14.**

*Scatterplots and Descriptive Statistics Teacher Experience and M1*

| Variables | Experience |
|---|---|
| M1 | 0.116* |
| M2 | -0.115* |
| M3 | 0.025 |
| M4 | -0.069 |
| M5 | -0.004 |

| Experience | (M1) Discovery Learning | |
|---|---|---|
| | <.5 the time | Total |
| < 15 years | 2 | 2 |
| ≥15 years | 2 | 2 |
| Total | 4 | 4 |



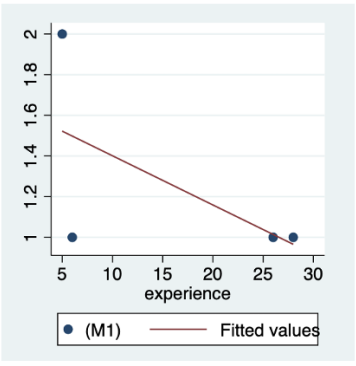



Figure 4.15 shows a statistically significant positive association between non-White teachers and the use of technology for (M1), which is inverse to the trend of the case study White teachers' use of technology. This is not a surprising discrepancy, given the minimal number of participants in the case study.

**Figure 4.15.**

*Correlations and Bar Chart of Teacher Race and M1*

Survey

| Variables | M1 |
|---|---|
| White | -0.220* |
| NonWhite | 0.220* |

Case Study

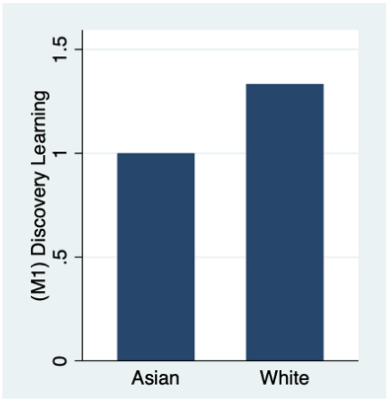



Figure 4.16 Survey results show that graduate degree holders tend to use technology for discovery learning (M1), which is consistent with the case study. This could indicate alignment between reported and actual teaching practice.

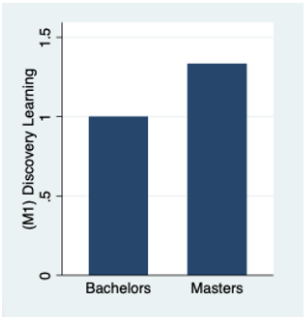
**Figure 4.16.**

*Correlations and Bar Chart Teacher Education Attainment and M1*

Survey

| Variables | M1 |
|---|---|
| Undergrad | -0.157* |
| Graduate | 0.157* |

Case Study



***Alignment: Confident teachers (S1 and S2) use technology for discovery learning.***

Table 4.6 shows the alignment between the survey and case study findings on S1 and M1. The survey findings show that the majority (80%), close to 100% (4/4) of the case study teachers report some level of confidence in their S1. This indicates that teachers are gaining confidence in their ability to design and select tasks with technology in instruction. Furthermore, survey teachers show a statistically significant moderate positive association between (S1, M1) and (S2, M1). However, because 75% (3/4) of the case study teachers professed to use technology for M1 but only 50% (2/4) were observed to use it, some evidence of discrepancy within the case study, but this is not surprising, given the small sample size for the case study.

This alignment between the teacher's confidence and the use of technology for discovery is helpful for future courses of action (i.e., policy, math education program course offerings, professional development training).

**Table 4.6.**

*Joint Display for Self-Efficacy (S1 and S2) MOTU for Discovery Learning (M1)*

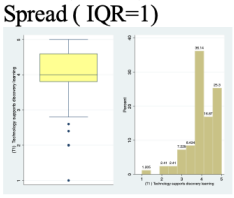
| **QUANT** | **QUALITATIVE Teacher Responses** | | **Metainference(s)Mixed Methods Interpretation** |
|---|---|---|---|
| Descriptive Statistics | Teacher Quotes | What and How Technology Is used | Align/discrepant/expansion |
| S1 and S2, skewed left<br>S1, Median=4<br>IQR=1<br>S2, Median=4.25<br>IQR=1<br>(M1) Discovery Learning<br>r=.293* (S1)<br>r=.255* (S2)<br><br>At 0.1 alpha level, there is a statistically significant moderate positive association between teacher confidence in their ability for tasks selection (S1) and (S2) lesson design and implementation and use of technology for **(M1) discovery learning.** | **Jacob moderate confidence**<br>"… when I first started using it,… I felt like I was spending hours editing the activity builders and inserting different questions. And like, oh, that actually looks horrible. I need to do something like it just I feel like it took a long time to figure out…(Follow-up Interview)<br><br>**Dana moderate confidence**<br>Dana "the first time was always iffy and that the next time was always better"( Initial Interview)<br><br>**Shiela moderate confidence**<br>-The doc (document) cam I use every day, so I'd say a 5 (extremely comfortable… --<br>-With Desmos, I've tried the coding aspect of it. I'm not as good on that part, so maybe a three (somewhat comfortable)<br>-Quizziz- probably a 4 (very comfortable). I've never done a lesson with it, but I use it for like Precalc as their daily quiz, so that's about it." (Follow-up Interview, October 12, 2023)<br>-Student teaching experience was influential in what technology and how she uses it in her practice<br><br>**Jona high confidence**<br>-a 4 in a scale of 1-5, 1-being the least and 5-being the most comfortable." (Follow-up interview, October 15, 2023)<br><br>**Jacob moderate confidence**<br>"I asked questions to Algebra 2 last time about solving a system with a quadratic and linear equation and I felt like I was able to do that because if they weren't able to do it algebraically, they had been instructed on how to graph it on a calculator and how to trace it and find their points."… "I feel like I've done a better job of really utilizing some of the extra capabilities of like the TI-84, which I know is an old calculator, but I have the software now, so it's a lot easier to project onto the board what I'm doing and the kids can follow along and it's changed the way I assess." (Jacob, Follow-up Interview)<br><br>Jonna attributed her high confidence<br>"I have a very nontraditional Uh experiences with teaching on how to do math. (Follow-up Interview, October 15, 2023) | Desmos for discovery learning, multiple representation, practice, individual learning, and reflection (Jacob, Classroom Observation)<br><br>TI-84 for multiple representation (Jacob, Follow-up Interview)<br><br>Desmos for discovery learning, multiple representation, practice, individual learning, and reflection (Dana, Classroom Observation)<br><br>Deltamath for practice (Follow-up Interview)<br><br>TI-84 for practice/do math and multiple representation<br><br>Desmos for practice and do Math<br>-review skills from the past lesson (Shiela, Class Observation)<br><br>TI-84 to practice and do Math<br>-calculate the unknown value (Shiela, Class Observation)<br><br>IXL for practice and do the Math<br>-individually assign students with problems to practice skills (Shiela, Follow-up Interview)<br><br>Microsoft Excel for multiple representation (Classroom Observation)<br>Desmos for discovery (Initial and Follow-up Interview)<br><br>Matthia for practice and individual learning (Follow-up Interview) | **ALIGNED**<br>**Self-confidence Survey Results**<br>Majority (more than 80% ) of the survey participants indicate some level of confidence in S1 and S2<br><br>All four (100%) of the case study participants report some confidence (moderate-high) in S1 or S2.<br><br>**Self-confidence and MOTU**<br>Survey findings indicate that when teachers are confident in S1 and S2, they tend to use technology for (M1).<br><br>**Case study findings indicate**<br>50% (2/4) of the participants used technology for discovery learning. (Jacob, Dana,) |

***Belief about technology supports discovery learning (T1) and technology used for discovery learning (M1).*** Table 4.7 shows evidence of alignment between the survey and case study findings. 75% of the survey and 100% of the case study teachers agree that technology supports discovery learning (T1). In addition, a statistically significant moderate (r=0.340*) positive

association exists between T1 and M1. This means survey teachers, like 50% of the observed case study teachers, tend to use technology for discovery learning (M1), which indicates **alignment.** This could also indicate that reported and actual teaching practices regarding technology use for discovery learning are almost congruent. This is interesting to investigate further! It could help guide actions (i.e., policy or program offerings or professional development)

**Table 4.7** Joint Data Display for T1 and M1

*Joint Data Display for Belief that technology supports discovery learning (T1) and M1*

| **QUAN** | **QUAL Teacher Responses** | | **Metainference(s) Mixed Methods Interpretation** |
|---|---|---|---|
| **Descriptive Statistics** | **Teacher Quotes** | **What and How Technology Is used** | **Align/discrepant/exexpansion** |
| T1 skewed to the higher values<br><br>Center(Med=4)<br>Spread ( IQR=1)<br>  <br><br>(T1, M1)<br><br>R=.340* | Dana was using Desmos to introduce exponential functions starting with geometric sequences which is a review from Algebra 1. The Desmos activity led the students to discover the formula for the exponential function including the growth and decay. The lesson posed leading questions such as "what do you notice and wonder" and then they were asked to write their observations" which is then shared to the class (Classroom Observation)<br><br>**Jacob** said that activities that use tools (Desmos and graphing calculators) "help students in conceptualizing the connection and that later on allow them to desctibe algebraic and graphical changes without the use of technology" (Initial Interview, Jan 2022).<br><br>Shiela responded that<br>-And that was when Agilemind (an a teaching software) was still a thing. So we have, like the demonstrations of like cutting a circle and it like pulled it. Open it up and like and gives you the area." (Follow-up Interview, October 12, 2023)<br><br>Jona's initial interview responses<br>-with Desmos students can play with learning" | Desmos for all MOTU Deltamath for M3 practice (Follow-up Interview)<br><br>TI-84 for practice/do math and multiple representation<br><br>Desmos- all MOTU (Jacob, Classroom Observation)<br><br>TI-84 for multiple representation (Follow-up Interview)<br><br>Desmos for M3 (Class Observation)<br><br>TI-84 M3 (Class Observation)<br><br>IXL M3 ( Follow-up Interview)<br><br>Microsoft Excel M2 (Classroom Observation)<br><br>Desmos for M1 (Initial and Follow-up Interview)<br><br>Deltamath Matthia M3 AND M4 (Follow-up Interview) | **Quantitiatve survey findings indicate that**<br>✓ Over 75% of the teachers agree that technology supports discovery learning<br><br>✓ There is a statistically significant moderate positive association between T1 and M1, Meaning, when teachers believe that T1 they tend to use it for M1.<br><br>**Case study findings indicate that**<br><br>✓ 100% (4/4) teachers believe that technology is great for discovery learning.<br><br>✓ 50% of case study teachers were observed to use technology for M1 |

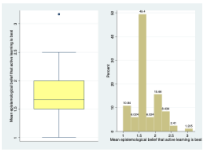
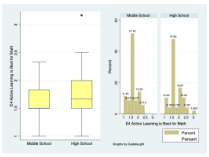
***Alignment: Teacher pedagogical beliefs lend to technology use for Discovery Learning (M1)***

Table 4.8 shows some discrepancies between the survey and case study findings, but they are not surprising due to the sample size. The survey findings indicate that teachers predominantly believe math is best learned via teacher direction (E3), and the opposite is that only a handful believe that math is best learned via active inquiry (E4). On the case study side, there is a 50-50 split. This means that 2/4 of the teachers agree with E3, and 2/4 agree with E4 or show evidence of more dynamic or eclectic views of the best way to learn math. This **discrepancy** is not surprising, given the small sample (4) of case study participants in high school.

But what is exciting is that it turns out that pedagogical beliefs do not matter when teaching with technology because teachers from both sides agree that technology is best for discovery learning. A small yet statistically significant positive association exists when (E3) is correlated with technology use for (M1) discovery learning (active inquiry). $r = 0.167\ *)$ ; a statistically significant small positive association exists when (E4) is correlated with technology use for (M1) discovery learning ($r = 0.191\ *$). And this is in **alignment** with the 50% (2/4) of the case study participants (Dana and Jacob) who were observed using technology (i.e., Desmos) in discovery learning.

**Table 4.8.**

*Joint Display for Epistemic Beliefs and MOTU*

| **QUANTITATIVE** | **QUALITATIVE Teacher Responses** | | **Metainference(s) Mixed Methods Interpretation** |
|---|---|---|---|
| **Descriptive Statistics** | **Teacher Quotes** | **What and How Technology Is used** | **Align/discrepant/ expansion** |
| (E4) Skewed distribution via active inquiry; a low center (Median < 2, IQR=1).<br>  <br>  <br>At 0.1 alpha level, R=0.191* (E4, M1) **(E4) active learning and (M1) discovery learning** | Jacob, teaching is "the instruction and guidance to developing new knowledge and skills for learners to use in new situations". (Initial Interview, January 2022) … "monitoring and guiding students through questioning as they navigate new situations". (Initial Interview, January 2022)<br><br>To Jacob, the best way to teach/learn mathematics is<br>-through a context, instruction, examples, and then individually practicing using the concepts of instruction in similar and different ways.<br><br>**Dana initial interview**<br>teaching as a process of<br>-transferring of information, knowledge, skills, and experiences"<br>-facilitating the learning…<br>-through your activities, … a group work perhaps. So, I may<br>not be directly teaching them, but they are Working together so that teaching is like a facilitation. That's one way…<br>-imparting mathematical concepts and skills … and<br>-help them develop logical and analytical thinking."<br><br>Dana in her follow-up interview reported that "…learning takes place when<br>-students interact with each other. So -not just by listening to the teacher.<br>-they form groups and when they discuss content…writing notes. So those things that<br>-collaboration is also part of learning. | Desmos for discovery learning, multiple representation, practice, individual learning, and reflection (Jacob, Classroom Observation)<br><br>TI-84 for multiple representation (Follow-up Interview)<br><br>Desmos for discovery learning, multiple representation, practice, individual learning, and reflection (Dana, Classroom Observation)<br><br>Deltamath for practice (Follow-up Interview)<br><br>TI-84 for practice/do math and multiple representation | **Quantitative survey results indicate that:** The survey findings indicate that most teachers disagree that math is best learned via active inquiry or student-centered practices.<br><br>**Case study findings indicate that**<br><br>50% (2/4) of the case study teacher HINTED that Math is best learned via active inquiry<br><br>**Discrepant:** 100% indicated to benefit/agree that technology for deeper conceptual understanding.<br><br>**Aligned**:<br>Survey: At 0.1 alpha level, there is **a statistically significant positive** association between math is best learned via **(E4) active learning and (M1) discovery learning**.<br><br>Case Study: 50% observed to use technology for (M1) discovery learning. |

***Misaligned/Discrepant: Teacher-centered instructors use technology as an instructional supplement.***

Table 4.9 shows inconsistency in the survey and case study for teacher-centered belief and mode of technology use. This is not surprising, given the case study sample size. The survey findings indicate that teachers who believe math is best learned via teacher direction show a statistically significant moderate negative association with multiple representations (M2) and individual learning (M4). In other words, the survey teachers generally avoid using technology

for all modes of technology use, even more so for M2 and M4. This is curious, given the 1-technology initiative.

In the meantime, the case study teachers (2/4) who seemed to adhere to teacher-centered beliefs were observed to use technology for (M2) multiple representations, (M3) practice, and (M4) individual learning. They were both at the center of the class, providing direct instruction, but at different points; for example, Sheila started class using Desmos for students to practice skills; she used a graphing calculator (TI-84) to serve as a calculation tool. Jona, on the other hand, was conducting direct instruction to explain the lesson at hand and used technology (i.e., Microsoft Excel) to construct boxplots (M2) and calculate numerical summaries (M3/do the math). While the incongruence between the survey report and case study could be due to the small sample size and the grade level taught, it could be something else and, therefore, worth investigating.

Table 4.9. Joint Display for Belief that teacher direction is best (E3) and MOTU

*Joint Display for Belief that teacher direction is best (E3) and MOTU*

| **QUAN** | **QUAL Data** | | **Mixed Methods Meta inferences** |
|---|---|---|---|
| **Descriptive Statistics** | | | **Align/discrepant/expansion** |
| Refer to Figure 4.14<br>The right skewed distribution of (E3) indicates that most teachers believe math is learned best via teacher direction.<br><br>E3 Teacher Direction<br>-0.200* (M2)<br>-0.293* (M4)<br><br>At 0.1 alpha level, there is a statistically significant negative association between (E3) and (M2) and (M4) | Jacob, eclectic (E3/E4) initial interview response<br>teaching is the "instruction and guidance to developing new knowledge and skills for learners to use in new situations" …<br>"Through a context, instruction, examples, and then individually practicing using the concepts of instruction in similar and different ways"<br>"Monitoring and guiding students through questioning as they navigate new situations".<br><br>Dana (eclectic) (E3/E4) initial interview<br>"Teaching as a process of transferring of information, knowledge, skills, and experiences"<br>"The usual structure for teaching is... facilitating the learning…<br>- I am discussing a lesson so that's pretty much transferring that information to the kids.<br>-for structures in the classroom ... means of transferring those knowledge…a group work. (Dana, Follow-up Interview)<br><br>Shiela, teacher centered (E3)<br>to teach mathematics is to "show and explain how to do a certain process" (Initial Interview); to give students similar problems to try out after she shows them the how<br>way to learn mathematics is via discovery and lots of practice, movement and collaboration<br>"Gaining skills through watching, listening, and/or doing something".<br><br>Jona, teacher centered (E3)<br>-Teachers are to provide materials, organize lessons and manage experiences<br>-teachers need to know how to manage and navigate those experiences." (Initial Interview, January 2022)<br>-some of our lower levels student sometimes direct instruction is better<br>-Sometimes they need the direct and sometimes they really need to build that stuff..." (Follow-up Interview, October 15, 2023) | Desmos for all MOTU (Jacob, Classroom Observation)<br><br>TI-84 for M2 (Follow-up Interview)<br><br>Desmos for all MOTU (Dana, Classroom Observation)<br><br>Deltamath for M3 and M4 (Follow-up Interview)<br><br>TI-84 for M2 and M3<br><br>Desmos for M3 (Shiela, Class Observation)<br><br>TI-84 to M3 (Shiela, Class Observation)<br><br>IXL for M3 and M4 (Shiela, Follow-up Interview)<br><br>Microsoft Excel M3 and M4 Classroom Observation)<br><br>Deltamath Matthia M3 and M4 (Follow-up Interveiw) | **Align:**<br>Majority (more than 75%) agree that math is best learned via teacher direction<br><br>Case study findings: 100% (4/4) believe that math is learn best both using teacher direction. (eclectic)<br><br>**QUAN** Survey participants indicate that<br>When teachers agree that math is learned best via **teacher direction,** they tend to **avoid** using technology especially for M2 and M4.<br><br>**Discrepant:**<br>Case study findings indicate<br>75% (3/4) of the participants use technology for multiple representation (Jacob, Dana, Jona)<br>100% (all 4) used technology for practice (Jacob, Dana, Jona, Shiela)<br>100% (3/4) of the participants used technology for individual learning (Dana, Jona, Shiela, Jacob)<br>50% (2/4) of the participants used technology for reflection ((Jacob, Dana |

## Summary

This chapter discussed the study findings, beginning with the quantitative, followed by the qualitative, and then finally, the mixed methods. The quantitative strand included descriptive statistics (numerical and graphical) and interpretation in context. Here, we found that survey teachers tend to use technology for discovery learning (M1). The qualitative strand reports the uncovered themes and subthemes—direct quotes from the case study teacher participants. Here, we found that case study teachers also tend to use technology for discovery learning, especially for those with eclectic/dynamic views of learning math.

The mixed methods include the joint display of evidence from quantitative and qualitative findings, which are compared, allowing for alignment or discrepancies to emerge. Here, we found that both the survey and case study teachers tend to use technology for discovery learning.

This discussion leads to Chapter 5, which begins with a summary of the main findings from each strand and the combined results from the joint analysis. The discussion of the driving forces for the tendency to use technology for discovery learning will be in the next chapter. Then, the study's implications, limitations, and conclusions are discussed.

# Chapter 5 - Discussion

## Introduction

This mixed methods study explored how secondary mathematics teachers' mode of technology use relates to their characteristics, multi-dimensional and sub-dimensional beliefs about teaching with technology, self-efficacy beliefs, and epistemic beliefs. The quantitative strand of this study used a voluntary and anonymous electronic survey administered via Qualtrics and sent to secondary math teachers from a large district in the Midwest USA via electronic mail. For the qualitative strand, a single case study (one school) with four (4) high school teacher participants in the district. These teacher participants were purposefully selected to ensure that they use technology in their teaching practice. The data collection methods included an initial open-ended interview, a semi-structured follow-up interview, and one or two classroom observations, as needed.

The order of discussion of findings begins with a summary of quantitative findings, followed by a summary of qualitative findings, and then the joint findings, which discuss alignment and complementary findings, implications, limitations, and conclusion.

## Summary of Findings

The quantitative strand **SubRQ1** revealed that teachers' characteristics have an inconsequential role in teachers' mode of technology use. While it appears that teacher age and length of experience drive teacher technology use for discovery learning (M1) and multiple representations (M2), it does not for all the other constructs. Aside from this, nothing else that can be considered necessary now stands out. **SubRQ2** showed that teacher beliefs about teaching with technology play a central role in teachers' use of technology for discovery learning (M1) since this dimension, and all the subdimensions included, show a statistically significant positive

relationship with the use of technology for discovery learning. **SubRQ3** revealed that teacher self-efficacy beliefs play an equally important role in technology use for discovery learning (M1). Both subdimensions showed a statistically significant positive association between technology use for discovery learning (M1) and teacher self-efficacy belief in selecting and designing tasks with technology (S1) and designing and implementing lessons (S2) with technology for discovery learning (M1). **SubRQ4** reveals that reported teacher pedagogical beliefs (i.e., Math is learned best via teacher-direction (E3) and active inquiry (E4)) show small but positive associations with technology use for discovery learning (M1). Teacher belief about the nature of math (i.e., math is rules and procedure (E1) or active inquiry (E2)) shows a small negative association with technology use for discovery learning (M1).

As for the qualitative strand, **SubRQ5** uncovered three underlying themes; these included: (1) teachers' self-efficacy beliefs about technology align with their classroom practice; (2) teachers' beliefs about how math should be taught may direct their adoption of technology in the classroom with two subthemes: (1) teacher-centered instructors used technology as an instructional supplement; (2) student-centered instructors use technology to facilitate learning; and (3) If teachers believe technology fosters positive teaching practices, they are more likely to adopt with five subthemes: (1) general benefits to teaching practice, (2) discovery learning, (3) multiple representation, (4) practice or do math, and (5) individual learning. Finally, **SubRQ6** found two barriers to technology use in the classroom- barriers internal to the teacher and external to the teacher.

**Alignment**

This discussion in this section includes the overarching themes, implications, recommendations for future research, limitations, and conclusion. The themes came from the

joint analysis of the qualitative and quantitative findings. Three uncovered themes include: (1) Discovery learning being the primary reported mode of technology use, and (2) Teacher characteristics have mixed results in the mode of technology use.

***Discovery learning (constructivist practices) is the primary mode of technology use***.

Discovery learning is a method that takes the constructivist approach to education. Cottrill (2003) explained that constructivism is a learning theory that the individual constructs a person's knowledge. It is presumed to take on Piaget's learning theory emphasizing the four stages of cognitive development (indicating that all learners go through different modes of thought in a particular order). In this theory, secondary mathematics students are called formal operational thinkers. The learners in this stage can think abstractly and understand the form or structure of a mathematical problem.

So, how does technology support constructivist teaching practices? As Piaget theorized, humans gain knowledge through their interactions with the environment, which shapes their mental structures for learning. Maria Montessori created a prepared environment where sensorial materials (i.e., manipulatives) facilitate learning. She hoped that these materials would enable students to take control of the learning process and learn via personal investigation and manipulation. Very recently, technology has since gained popularity for its potential not only as a (virtual) manipulative that allows students to explore ideas and engage them in different ways of representing concepts (i.e., simulation, graphical, numerical) but also for its embedded computational and communication capabilities. These technological affordances support Piaget and Montessori's conception of student-centered learning. They enable the manipulation and extension of concepts that may be difficult or too abstract via other forms of representation, such as simulation, sliders, animations, and many other forms.

In support, the current case study teacher participants shared their thoughts. For example, graphing calculators create student-centered, discursive, and explorative approaches. Technology use allows students to "conceptualize the connection and eventually describe algebraic and graphical changes without the use of the technology." (Jacob, Initial Interview), and "technology helps students make connections" (Jacob, Follow-up Interview). A software called Agile Mind "like the demonstrations of… cutting a circle… open [ing it] up… gives … the area [of the circle]; helped me understand it [circles] better" (Sheila, Follow-up Interview). Students get to "explore with Desmos-find the reasons the math works" (Jona, Initial Interview). All these comments point to technology being used as a learning tool for conceptualizing mathematical ideas and connections via guided discovery, visualization, simulation, or representing concepts in different forms. In addition, there was also an added benefit: technology allows for gamification, making learning fun!

This study's findings significantly support the validity of Thurm and Barzel's (2021) study, which concluded that discovery learning is the primary mode of technology used in mathematics teaching and learning. This study also agrees with Schommer's (1990) claims on the multidimensionality of knowledge and learning by finding not one but two groups of teacher beliefs—the teacher's self-efficacy beliefs and beliefs about teaching with technology—that are powerful drivers for technology use for discovery learning (M1).

**Teacher Self-Efficacy as a driving force of technology use for discovery learning (M1).**

Klassen et al. (2009) and Klassen & Tse (2014) claimed that teachers' self-efficacy beliefs have a powerful influence over a teacher's behavior in the classroom and the effort they put forth in an endeavor. Now that this study has also found evidence supporting self-efficacy as one of the "missing links," what does this tell us? And how can we use this to improve teaching practice?

First, let us consider the primary sources of self-efficacy beliefs (self-confidence). **Personal mastery experience** topped the list for teacher behavior change (Bandura, 1997; Capa-Aydin et al., 2018). With the help of time and frequency of use, this helps build confidence—feelings of safety when experimenting and some freedom for instructional decisions. Consider case study teacher Dana, who admitted moderate confidence in using technology. She mentioned that "the first time was always iffy, and the next time was always better" (Initial Interview). Jacob also rated himself moderately confident with technology, recalling,

> When I… started using it [technology], …I spent hours editing the activity builders and inserting different questions. … it took a long time to figure out" …. "Having …more teaching experience…makes it easier to make an activity that targets…a specific skill or concept. (Follow-up Interview, October 12, 2023).

In 2018, Capa-Aydin talked about **vicarious experiences** being found useful when personal experience is lacking. Both novice and seasoned teachers look at others as models or guides, observe them, and compare them to their perceived abilities. The more the individual feels like the model, the stronger their sense of self-efficacy. Sheila, a case study teacher, is a perfect example of this case, recalled.

> And I mean, my CT [cooperating teacher] uses the doc cam, so I use the document camera. She used the smartboard, so I used the smartboard. She used Desmos, I use Desmos. I don't think Delta Math was a thing then, but we used it. She uses it quite a bit, so I used it quite a bit … it makes a lot of difference. (Follow-up Interview, October 12, 2023)

All of this support the idea of personal and vicarious experiences influencing the use of

technology among teachers. But, of course, other factors are at play. Bandura (1997, p. 240) suggested that creating learning environments that are conducive to learning rests heavily on a teacher's talents and self-efficacy. The lack of the necessary technology skills and the student reaction influenced technology integration practice. Sheila, who rated herself moderately confident, recalled teaching her precalculus [class] experience, where the students freaked and did not like the experience [, thus] had never used the technology in her classes that way again. At other times, when lesson planning using technology, she mentioned that.

> If I have to change the coding, it will be a no. There have been a few times where I pick a slide, and I copy it over, and I thought it was gonna do one thing, and it does something completely different, and my students freak out on me…. I like the ones where I can pull a question from this pool of questions and make my own on…Quizziz- probably a 4 (very comfortable). I've never done a lesson with it, but I use it for … Precalculus as their daily quiz, so that's about it. (Follow-up Interview, October 12, 2023)

Jona recalled having "a very nontraditional experience …teaching… math. They [the program she was in] were trying to teach us new ways to teach math… even though they did not teach me the technology aspect, [they did teach] the attitudes, the behaviors, the mentality, and the growth mindset…. T[hey] try whatever helps you model it. Hands-on experiences ... So even though it wasn't technology [specific], that … naturally evolved through time." (Jona, Follow-up Interview, October 15, 2023)

All this information may be helpful to guide future actions (e.g., professional development, course offerings) that might help shift or change teaching practice to more constructivist approaches by looking at changing teacher self-efficacy beliefs via personal and vicarious experiences (e.g., models) with time as a resource, access to appropriate,

encouragement on the frequency of technology use, a safe environment for experimentation, and freedom to make instructional decisions.

**Teacher beliefs about teaching with technology are an impetus for teachers' technology use (i.e., for discovery learning (M1).** This study's findings are significant and consistent with Russell, Bebell, O'Dwyer, and O'Connor's (2003) claim that the strongest predictor of technology use is the teachers' belief that technology benefits teaching and learning and specifically, with the previous study by Ertmer and Albion (2009), which found that teachers find technology a valuable instructional tool that supports their constructivist beliefs.

In the case study, teachers figured that technology could be an excellent tool for students to discover abstract mathematical concepts. In her initial interview, Dana thought that because of the "Desmos embedded functionality, student learning was … more engaging as students were allowed to express their understanding and thinking process and ultimately were allowed to share with the whole class". During the classroom observation in Algebra 2, a Desmos activity was used to guide students in discovering the formula for the exponential function, starting with geometric sequences, a review from Algebra 1.

In his follow-up interview, Jacob shared that technology allows students "access to a more interactive" experience and that he can pose "open-ended and probing questions to all students, and responses are shared with the rest of the class" ... "to express their findings in their own words and shared with the whole class." He noted that "activities with these tools help students conceptualize the connection and eventually describe algebraic and graphical changes without using the technology" (Initial Interview). This indicates that technology allows students to think or process problems or concepts that may help them in future related tasks even without technology. During classroom observation, Jacob employed technology (Desmos) so students

could discover the graph of exponential function and corresponding transformation by having them "explore how the points that satisfy the exponential function look graphically." All these lend support to Zhao, Pugh, Sheldon, & Bryers (2002), claim that when technology is viewed as a valuable pedagogical tool, teachers tend to use it more often and (Watson, 2006) determines how it is used, and in this case, more on constructivist approach.

There are many possible explanations for this phenomenon. One possible explanation could be, in the bigger scheme of things, that teachers are beginning to recognize the need for students to construct their knowledge through experiential learning instead of passively receiving it. In this way, teachers may feel that they are preparing learners for skills to be productive cocreators or co-constructors of knowledge- a valuable skill in this fast-changing, interconnected digital world. This explanation is timely, given that more jobs now and in the future will require general digital and mathematical competencies (BLS, 2021). As Richard Riley, former Secretary of Education, famously said, "We are preparing students for jobs that don't yet exist…using technologies that haven't been invented…to solve problems we don't even know are problems yet." This explanation supports Bray & Tangney's (2017) claims that pertain to taking advantage of digital tools with appropriate pedagogy to facilitate realistic, problem-solving, and collaborative approaches to teaching and learning.

Alternatively, this study's findings may be attributed to a contextual factor unique to this district. This pertains to the school district's adoption of student 1-1 (laptop) technology with provision for internet connectivity in the classroom and outside (via mobile cards for those with no access to the internet at home) in 2021, right after COVID-19. Simultaneously, teachers were issued a new Surface Pro (which functions as a tablet and laptop in one) with district in-service pieces of training that provided teachers, including mathematics teachers, with basic digital

technology skills to get them started. A few in-service math training pieces also provided basic training on tools like Desmos and other technologies (i.e., simulation tools).

***Teachers' pedagogical belief (i.e., Math is best learned via teacher direction or active inquiry (constructivist view) is directly linked to technology use for discovery learning***. This study finding is interesting as it is consistent with Ernest's (1989) argument that beliefs about teaching mathematics were more influential in a teacher's practice than their belief about the nature of mathematics and very well supports Thurm & Barzel's (2021) conclusion that teachers with a constructivist view and dynamic perspective tend to use technology for student-centered practices. Take these case study teachers, Jacob, and Dana, for example. While both noted for their seeming eclectic view of how math is learned best, Jacob said that technology helps "students conceptualize the connection and eventually describe algebraic and graphical changes without the use of the technology." Dana, in her pre-observation and initial interview responses, expressed that technology use provides students with "help in deepening understanding and providing more applications of concepts," allows students to "work interactively when doing exploratory work," allows for "enrichment lessons," and efficiently "assess students learning and give student feedback faster."

~~This is important to know! This could mean that no matter the instructional beliefs teachers hold about what is best, teachers find that technology is helpful for learning, particularly for constructivist implementations. The technology could make discovery learning manageable, efficient, and more, which makes sense given its capabilities (i.e., speed and accuracy, simulation, visual or other representations).~~

This finding is crucial as it supports Watson's (2006) proposition that a teacher's belief in the value of technology as a pedagogical tool determines how technology is used and, more

specifically, Ertmer and Albion's (2009) prior claim that teachers find technology a valuable instructional tool that supports constructivist practices.

**Complementary**

***Barriers to technology use are inevitable.*** The case study findings reveal two types of barriers- internal to the teacher ($2^{nd}$-order) and external to the teacher ($1^{st}$-order)- that hinder teachers from maximizing the potential benefits of technology in teaching and learning Mathematics. Those considered **internal to the teacher** and create discomfort in teachers' technology use include the lack of training from teacher preparation programs and the need for math-specific technology courses. Two of the case study teachers, both very recent graduates (within the last 5-6 years) from Math Education programs in the region, "would love to do like a Desmos coding" (Sheila, Initial Interview) or "separate class like technology in the mathematics classroom. We need a class over Desmos, and I don't know if Delta math existed at the time right, but Desmos, Delta[math], Quizziz… all those things we use in our math room regularly; it would have been beneficial if there was like a program for math teachers…This is how the Texas Instrument software looks, or this is … the math-specific things because … technology in education class. … was …generic like all the math or all education majors took it like elementary through high school no matter what." (Jacob, Follow-up Interview).

Secondly, barriers that are **external to the teacher**- considered beyond the teacher's control time as a resource include affordable access to appropriate technologies (i.e., subscriptions), access to quality, just-in-time resources, and technology user-friendliness for both teacher and student. Time is a resource that teachers do not have the luxury of, particularly when creating materials that are appropriate to the needs of their students. Hence, access to high-quality, just-in-time resources that are affordable and user-friendly is very important.

## Implications

This study's main finding, the use of technology for discovery learning as teachers' primary mode of technology use- sends an important message for the **secondary Mathematics education programs** (for middle and high school) to offer prospective secondary Mathematics teachers a Math-specific technology course(s) that provides them alternative visions of teaching with technology (Windschitl, 2002), such as a micro-teaching experience on unfamiliar teacher tasks when using technology in teaching, for example, "diagnosing and giving feedback to students without explaining the solution" (Thurm & Barzel, 2020), provide technical skills and know how to create and design lessons and tasks appropriate for their classroom needs (Hughes, 2005).

To **professional learning providers (PD) /developers**, this study's findings speak to creating PD training pieces to address the lack of technological readiness related explicitly to the teachers' grade-level content (i.e., micro-teaching experiences suggested above). **Policymakers and administrators** should continually assess the technology training and needs necessary to provide teachers with technical know-how to build confidence in integrating technology that promotes student-centered teaching and learning practice. Provide teachers with multiple models and opportunities (i.e., PD that caters to technology skills needs of Math teachers, peer observation opportunities within the school or outside) to practice technology with support. Allocate ample **time** for teachers (vary by teacher) to explore and experiment with technology use in a low risk setting. Consider self-paced PD-giving Inservice teachers' opportunities to reflect on their practice and their instructional outcome in mind. PD provides Inservice teachers time to observe teachers implementing technology in instruction and sustained training on software competency directly related to their teaching content. **Classroom mathematics**

**teachers should continue or consider exploring new technologies to address the different needs of student**s (i.e., historically marginalized, language learners, neurodivergent learners, and students with learning disability). Give yourself a chance to explore new technologies with peers, observe colleague(s) known to use technologies, or create teams within the department or even interdepartmental that meet regularly to explore new technologies that you find beneficial towards student-centered teaching and learning practices.

For future research, a quasi-experimental study will be conducted to increase teacher self-efficacy beliefs and beliefs about teaching with technology to implement treatment self-efficacy interventions or technology skills training. Data collection would include pre- and post-treatment surveys, interviews, and observation data.

A large-scale study investigating the role of teacher beliefs, characteristics, technical, mathematical, and pedagogical knowledge, and context in influencing teaching practice. The survey and case study should include students, paraeducators, and administrators to get a complete picture and differing perspectives.

## Limitations

Despite this researcher's meticulous planning, weaknesses resulting from limitations, including sample size and sampling techniques, omitted variable bias, and selection bias, are discussed below. **Sample Size and Sampling Techniques.** A few limitations that may affect the results of this study include a small sample size and the employment of nonrandom (voluntary) sampling techniques. A larger sample size could have made the survey findings more generalizable. A random sampling technique would have made the results less biased, if not unbiased. There are also anticipated **omitted variable biases** (i.e., mathematical knowledge, technical competency, social context) that are not included in this study that may have impacted

or skewed the results, and this is a suggestion for future researchers to consider. This is also why this study does not necessarily make causal predictions but mere correlations, so at least some evidence is established for a relationship in future studies.

**Selection bias** due to the lack of case study teacher participants from middle schools or other high schools that may have different social contexts (i.e., student demographics, school culture) known to impact teaching practice could make the study outcomes generalizable to other social contexts that impact teacher practices, particularly with technology.

Finally, there are **time** constraints, particularly during the case study. This resulted in a limited frequency of classroom observation, which may help capture a more accurate picture of the frequency of actual technology use.

Knowing ahead that there are limitations, hence the choice of a mixed methods designs for this study. At least in this way, methodological triangulation was employed to help elucidate the phenomenon under investigation with more depth and clarity.

## Conclusions

To conclude, teaching practices such as the mode of technology use are complex endeavors. Their implementation, particularly constructivist approaches (discovery learning (M1)), requires a mix of multidimensional teacher beliefs (i.e., self-efficacy beliefs, beliefs about teaching with technology, and pedagogical beliefs) and many more. For example, access to appropriate technologies. However, since there is no definite evidence that belief precedes or follows behavior, it is worth considering both in future planning and course of action. For example, we need to consider simultaneously, depending on the application, the most appropriate given the context.), while Pajares (1992) suggests that teacher behavior change precedes belief.

For example, access to appropriate technologies that support their instructional goals (i.e., Desmos activities) and domain-specific learning experiences (i.e., micro-teaching specific teacher jobs when using technology in teaching math) that is meticulously planned, starting with a low-risk environment to help build confidence (Thurm & Barzel, 2020). Like prior research, this study has also shown that successful initial personal experiences and vicarious experiences (i.e., with technology use) play pivotal roles in teacher behavior change (Bandura, 1997), so creating a learning environment where personal success is (almost) guaranteed is critical. In addition, an encouraging environment that exemplifies peer-to-peer observation with technology use is readily available or arrangeable, whether within the school or outside.

In addition, this researcher also found that access to appropriate technologies encourages dialectic teaching practices (i.e., case study teachers Jacob and Dana). This is congruent with Cross's (2009) study conclusion that teachers will use any tool perceived to help students learn (i.e., demonstrate an anticipated desired outcome) as well as Zhao, Pugh, Sheldon, & Bryers (2002) claims that the teacher's belief in the value of technology as a pedagogical tool for their goals makes them more likely to use it.

This phenomenon of technology use in a constructivist manner may indicate that secondary Math teachers are beginning to recognize the need to produce general digital and mathematically competent graduates. Some may even believe this is one of their duties in this ever-growing, interconnected digital world.

## References


Albion, Peter & Ertmer, Peggy. (2002). Beyond the foundations: The role of vision and belief in teachers' preparation for integration of technology. *TechTrends. 46*(5). 34-38. https://doi.org/10.1007/BF02818306

Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education, 5*(6), 66–70.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84(2), 191–215.https://doi.org/10.1037/0033-`295X.84.2.191

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191-215. https://doi.org/10.1037/0033-295X.84.2.191

Bandura, A. (1994). Regulative function of perceived self-efficacy. In M. G. Rumsey, C. B. Walker, & J. H. Harris (Eds.), *Personnel selection and classification*, 261–271. Lawrence Erlbaum Associates, Inc.

Bandura, A. (1997). Self-efficacy: The exercise of control. W H Freeman/Times Books/Henry Holt & Co.

Barni, D., Danioni, F., & Benevene, P. (2019). Teachers' self-efficacy: The role of personal values and motivations for teaching. Frontier Psychology. https://doi.org/10.3389/fpsyg.2019.01645

Berger, J., Girardet, C., Vaudroz, C., Crahay, M. (2018). Teaching experience, teachers' beliefs, and self-reported classroom management practices: A coherent network.

Bernard, H.R. (1995) Research Methods in Anthropology: Qualitative and Quantitative Approaches. Altamira Press, Walnut Creek.

Blömeke, S., Olsen, R.V., & Suhl, U. (2016). Relation of student achievement to the quality of their teachers and instructional quality. In:

Boddy, N., Watson, K. & Aubusson, P. (2003). A Trial of the five Es: A referent model for constructivist teaching and learning. Research in Science Education, 33, 27–42. https://doi.org/10.1023/A:1023606425452

Bos, Beth. (2008). Mathematical and cognitive fidelity, technology impacting mathematical achievement.

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research – A systematic review of recent trends. Computers & Education. 114.10.1016/j.compedu.2017.07.004.

Buabeng-Andoh, C. (2012). Factors influencing teachers' adoption and integration of information and communication technology into teaching: A review of the literature. *International Journal of Education and Development using Information and Communication Technology (IJEDICT)*, *8*(1), pp. 136-155

Capa-Aydin et al. (2018). The relationship between vicarious experience, social persuasion, physiological state, and chemistry self-efficacy: The role of mastery experience as a mediator. Psychology in Schools 55(10), 1224-1238. DOI: 10.1002/pits.22201

Cardellini, L. (2008). The views and influence of Ernst Von Glasersfeld: An introduction. Found Chem 10, 129–134. https://doi.org/10.1007/s10698-006-9022-x

Charmaz, K. (2005). *Grounded Theory in the 21st Century: Applications for Advancing Social Justice Studies*. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage Handbook of Qualitative Research*, 3, 507–535). Sage Publications Ltd.

Clark-Wilson, A., & Hoyles, C. (2017). Dynamic digital technologies for dynamic mathematics: Implications for teachers' knowledge and practice.

Clark-Wilson, A., Robutti, O., & Thomas M. (2020). Teaching with digital technology. *ZDM, 52*(7),1223-1242. Doi: 10.1007/s11858-020-01196-0.

Cobb, P., & Steffe, L. P. (1983). The constructivist researcher as teacher and model builder. *Journal for Research in Mathematics Education, 14*(2), 83–94. https://doi.org/10.2307/748576

Cottrill, J.B. (2009). An overview of theories of learning in mathematics education research. *Colección Digital Eudoxus*.

Creswell, J. W. (2005). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research.* Upper Saddle River, NJ: Pearson.

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory Into Practice, 39*(3), 124–130. http://www.jstor.org/stable/1477543

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research (2nd ed.)*. Sage Publications

Đerić, I., Elezović, I., Brese, F. (2022). Teachers, teaching, and student achievement. dinaric perspectives on TIMSS 2019. *IEA Research for Education,13*. 151-174. https://doi.org/10.1007/978-3-030-85802-5_7

Desimone, L., Porter, A., Garet, M, Yoon, K.S., & Birman, B. (2002). Effects of professional development on teachers' instruction: results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis*, 24(2), 81-112. https://doi.org/10.3102/01623737024002081

Devine, P. G., & Sherman, S. J. (1992). Intuitive versus rational judgment and the role of stereotyping in the human condition: Kirk or Spock? *Psychological Inquiry, 3*(2), 153-159. https://doi.org/10.1207/s15327965pli0302_13

Dick, T. P., & Hollebrands, K. F. (2011) *Focus on High School Mathematics.* National Council of Teachers of Mathematics. Reston, VA:

Dogan, S., Dogan, N.A. & Celik, I. (2021). Teachers' skills to integrate technology in education: Two path models explaining instructional and application software use. *Educ Inf Technol 26*, 1311–1332. https://doi.org/10.1007/s10639-020-10310-4

Drijvers, P., Ball, L., Barzel, B., Heid, M. K., Cao, Y., & Maschietto, M. (2016). Uses of technology in lower secondary mathematics education: A concise topical survey. Springer International Publishing AG.

Ernest, P. (1989). The Knowledge, beliefs, and attitudes of the mathematics teacher: a model. *Journal of Education for Teaching, 15*, 13-33. 10.1080/0260747890150102.

Ertmer, P., Ottenbreit-Leftwich, A., & Tondeur, J. (2016). Teacher beliefs and uses of technology to support 21st century teaching and learning. *International Handbook of Research on Teachers Beliefs, 1*, 403-419. https://www.researchgate.net/profile/Peggy-Ertmer/publication/312434657_Teachers'_beliefs_and_uses_of_technology_to_support_21st-century_teaching_and_learning/links/5890b5ba92851cda25689ccc/Teachers-beliefs-and-uses-of-technology-to-support-21st-century-teaching-and-learning.pdf

Ertmer, P. and Ottenbreit-Leftwich, A. (2010). Teacher Technology Change: How Knowledge, Beliefs, and Culture Intersect. *Journal of Research on Technology in Education, 42*, 255-284. 10.1080/15391523.2010.10782551.

Ertmer, Peggy. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research & Development. 53*. 25-39. 10.1007/BF02504683.

Ewald, T. (2011). Has John Hattie really found the holy grail of research in teaching? An extended review of visible learning, *Journal of Curriculum Studies, 43*(3), 425-438, DOI: 10.1080/00220272.2011.576774

Fives, H., & Gill, M.G. (2014). International handbook of research on teachers' beliefs.

Gal, P., Nicoletti, G., von Rüden, C., Sorbe, S., & Renault, T. (2019). Digitalization and productivity: In search of the holy grail - firm-level empirical evidence *International Productivity Monitor, Centre for the Study of Living Standards, 37*, 39-71.

Geiger K.B., Carr, J.E, Leblanc, L. (2010) Function-based treatments for escape-maintained problem behavior: a treatment-selection model for practicing behavior analysts. *Behavioral Analysis in Practice. Spring;3*(1), 22-32. doi: 10.1007/BF03391755. PMID: 22479669; PMCID: PMC3004681.

Geiger, B. (2000). Discipline in K through 8th grade classroom. *Education, 121*(2), 383-393.

Geraniou, E., Jankvist, U.T. (2019). Towards a definition of "mathematical digital competency." *Educ Stud Math 102*(1), 1-17. https://doi.org/10.1007/s10649-019-09893-8

Godwin, S., & Sutherland, R. (2004). Whole class technology for learning mathematics: The case of functions and graphs. *Education, Communication & Information, 4*(1), 131–152. DOI: 10.1080/1463631042000210953

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research, 3*, 105–117.

https://ethnographyworkshop.files.wordpress.com/2014/11/guba-lincoln-1994-competing-paradigms-in-qualitative-research-handbook-of-qualitative-research.pdf

Hattie, J. & Zierer, K. (2018). *Ten Mindframes for Visible Learning: Teaching for Success.* Routledge.

Hellström, Tomas. (2008). Transferability and Naturalistic Generalization: New Generalizability Concepts for Social Science or Old Wine in New Bottles? *Quality and Quantity. 42*(3). 321-337. 10.1007/s11135-006-9048-0.

Hodges, F. M. (2003). The promised planet: Alliances and struggles of the gerontocracy in American television science fiction of the 1960s. The Aging Male, 6(3), 175-182.

Hohenwarter, M. & Preiner, J. (2007). Dynamic Mathematics with GeoGebra. *Journal of Online Mathematics and its Applications 7*(1), 2-12. http://article.sciappliedmathematics.com/pdf/AJAMS-6-3-5.pdf

Honebein, P.C. (1996). Seven goals for the design of constructivist learning environments.

Hwang, N. & Fitzpatrick, B. (2021). Student-teacher gender and academic achievement. AERA Open,7. https://doi.org/10.1177/23328584211040058

Inan, F., & Lowther, D. (2010). Factors affecting technology integration in K-12 classrooms: A path model. Educational Technology Research and Development, 58(2), 137-154.

Innes, Robert B. (2007) "Dialogic Communication in Collaborative Problem-Solving Groups, "International Journal for Scholarship of Teaching and Learning: Vol. 1: No. 1,

International Society for Technology Education. (n.d.) ISTE standards: Students.https://www.iste.org/standards/iste-standards-for-students

James, N. E. (1988). Two sides of paradise: The Eden myth according to Kirk and Spock. In D. Palumbo (Ed.), Spectrum of the fantastic (pp. 219-223). Westport, CT: Greenwood.

Kim, C.M., Kim, M.K.; Lee, C., Spector, J. M, DeMeester, K. (2013). Teacher beliefs and technology integration. *Teaching and Teacher Education: An International Journal of Research and Studies*, 29,76-85. http://dx.doi.org/10.1016/j.tate.2012.08.005

Klassen, R. M., & Tze, V. M. C. (2014). Teachers' self-efficacy, personality, and teaching effectiveness: a meta-Analysis. *Educational Research Review, 12*(4), 59-76. https://doi.org/10.1016/j.edurev.2014.06.001

Klassen, Robert & Bong, Mimi & Usher, Ellen & Chong, Wan Har & Huan, Vivien & Wong, Isabella & Georgiou, Tasos. (2009). Exploring the validity of a teachers' self-efficacy scale in five countries. *Contemporary Educational Psychology*. *34*(*1)*. 67-76. 10.1016/j.cedpsych.2008.08.001.

Lapan, R. T. (2004). Career development across the K-16 years: Bridging the present to satisfying and successful futures. *American Counseling Association*.

Lavicza, Z. (2010). Integrating technology into mathematics teaching at the University level. ZDM *Mathematics Education 42*, 105–119. https://doi.org/10.1007/s11858-009-0225-1

Lin, X., Hmelo, C., Kinzer, C.K. (1999). Designing technology to support reflection. *ETR&D, 47*, 43–62. https://doi.org/10.1007/BF02299633

McFarland, J., Hussar, B., Zhang, J., Wang, X., Wang, K., Hein, S., Diliberti, M.K., Cataldi, E.F., Mann, F.B., & Barmer, A. (2019). The Condition of Education 2019. NCES 2019-144. *National Center for Education Statistics*. Retrieved [date] from https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2019144.

McKnight, K., O'Malley, K., Ruzic, R., Horsley, M.K., Franey, J.J., & Bassett, K. (2016). Teaching in a digital age: How educators use technology to improve student learning.

*Journal on Research on Technology in Education, 48*(3), 194-211. https://doi.org/10.1080/15391523.2016.1175856

Mujis, D., & Reynolds, D. (2015). Teachers' beliefs and behaviors: What really matters? *Journal of Classroom Interaction, 50*, 25-40.

National Council of Teachers of Mathematics. (2014). Principles to actions: Ensuring mathematical success for all. https://doi.org/10.20429/ijsotl.2007.010104

Nilsen, T., Gustafsson, J.E. (2019). Teacher quality, instructional quality, and student outcomes. *IEA Research for Education, 2*. https://doi.org/10.1007/978-3-319-41252-8_2

Parker, C.E., Stylinski, C.D., Bonney, C.R. et al. (2019). Measuring Quality Technology Integration in Science Classrooms. *J Sci Educ Technol 28*, 567–578. https://doi.org/10.1007/s10956-019-09787-7

Philipp, A. (2007). Mathematics teachers' beliefs and affect. In F. K. Lester (Ed.), Second handbook of research on mathematics teaching and learning. Reston: National Council of Teachers of Mathematics.

Poirier, M., Law, J.M., & Veispak, A. (2019). A spotlight on lack of evidence supporting the integration of blended learning in K-12 education: A systematic review. *International Journal of Mobile and Blended Learning, 11*(4), 1-14. https://doi.org/10.4018/IJMBL.2019100101

Ringstaff, C. & Kelley, L. & Rtec, Wested. (2002). The Learning Return on Our Educational.

Roberts, D.L. (2014). History of Tools and Technologies in Mathematics *Education. Handbook on the History of Mathematics Education*. Springer, New York, NY.

Roberts, R. E. (2020). Qualitative Interview Questions: Guidance for Novice Researchers. The Qualitative Report, 25(9), 3185-3203. https://doi.org/10.46743/2160-3715/2020.4640

Russell, M., Bebell, D., O'Dwyer, L., & O'Connor, K. (2003). Examining teacher technology use: Implications for preservice and inservice teacher preparation. Journal of Teacher Sage Journals, 8(1), https://doi.org/10.1177/2158244017754119

Schensul, S., Schensul, J., & LeCompte, M. D. (1999). *Essential ethnographic methods*. London: Altamira Press.

Scherer, R. & Siddiq, F., & Teo, T. (2015). Becoming More Specific: Measuring and Modeling Teachers' Perceived Usefulness of ICT in the Context of Teaching and Learning. Computers & Education. 88. 10.1016/j.compedu.2015.05.005.

Schleicher, A. (2018). Educating learners for their future, not our past. ECNU

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*(3), 498–504. https://doi.org/10.1037/0022-0663.82.3.498

Selwyn, N. (2011). Education and Technology: Key Issues and Debates. Continuum International Publishing Group, London.

Shah, R., Gundotra, N., Abbeel, P. & Dragan, A. (2019). On the feasibility of learning, rather than assuming, human biases for reward inference. Proceedings of the 36th International Conference on Machine Learning, in Proceedings of Machine Learning Research 97:5670-5679 Available from https://proceedings.mlr.press/v97/shah19a.html.

Siddiq, F., Scherer, R. (2016). The relation between teachers' emphasis on the development of students' digital information and communication skills and computer self-efficacy: the moderating roles of age and gender. *Large-scale Assess Educ 4*(1), 1-21. https://doi.org/10.1186/s40536-016-0032-4

Simonsen, L.M. & Dick, T.P. (1997). Teachers' Perceptions of the Impact of Graphing Calculators in the Mathematics Classroom. Journal of Computers in Mathematics and Science Teaching, 16(2), 239-368. Charlottesville, VA: Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/p/20948/

Snider, S. & Hirschy, Sharon. (2009). A self-reflection framework for technology use by classroom teachers of young learners. He Kupu. 2.

Spotts, T.H., Bowman, M.A. & Mertz, C. (1997). Gender and use of instructional technologies: A study of university faculty. Higher Education 34, 421–436. https://doi.org/10.1023/A:1003035425837

Stake, R. E. (1995). *The art of case study research*. Sage Publications, Inc.

Steffe, L., & Kieren, T. (1994). Radical Constructivism and Mathematics Education. Journal for Research in Mathematics Education. 25. 711. 10.2307/749582.

Suárez-Guerrero, C., Rivera-Vargas, P., & Raffaghelli, J. (2023). EdTech myths: towards a critical digital educational agenda. Technology, Pedagogy and Education, 32(5), 605-620.

Supovitz, J., & Turner, H. (2002). The Effects of Professional Development on Science Teaching Practices and Classroom Culture. *Journal of Research in Science Teaching. 37*(9). 10.1002/1098-2736(200011)37:93.0.CO;2-0.

Tamam, B. & Dasari, D. (2021). The use of GeoGebra software in teaching mathematics. Journal of Physics

Teachers. International Journal of Science and Mathematics Education. 19: 747-769.DOI: 10.1007/s10763-020-10074-w

Thompson, A. G. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In D. A Grouws (Ed.), Handbook of research on mathematics teaching and learning: A project of

the National Council of Teachers of Mathematics (pp. 127–146). Macmillan Publishing Co, Inc.

Thompson, P.W. (2020). Constructivism in Mathematics Education. In: Lerman, S. (eds) Encyclopedia of Mathematics Education. Springer, Cham. https://doi.org/10.1007/978-3-030-15789-0_31

Thurm, D. (2017). Scales for measuring teacher beliefs in the context of teaching mathematics with technology. Online under: https://nbn- resolving.org/urn: nbn:de: hbz:464-20201208-145052-1.

Thurm, D. (2018). Teacher beliefs and practice when teaching with technology: A latent profile analysis. In L. Ball, P. Drijvers, S. Ladel, H.-S. Siller, M. Tabach, & C. Vale (Eds.), Uses of technology in primary and secondary mathematics education (pp. 409–419). Cham: Springer.

Thurm, D. & Barzel, B. (2020). Effects of a professional development program for teaching mathematics with technology on teachers' beliefs, self-efficacy, and practices. *ZDM Mathematics Education* 52, 1411–1422. https://doi.org/10.1007/s11858-020-01158-6

Thurm, D., & Barzel, B. (2019). Self-efficacy—The final obstacle on our way to teaching mathematics with technology? In U. T. Jankvist, M. van den Heuvel-Panhuizen, & M. Veldhuis (Eds.), Proceedings of the eleventh congress of the European Society for Research in Mathematics Education (pp. 2749–2757). Utrecht: Freudenthal Group and ERME.

Thurm, D., & Barzel, B. (2021) Teaching mathematics with technology: a multidimensional analysis of teacher beliefs. Educ Stud Math 109, 41–63 (2022). https://doi.org/10.1007/s10649-021-10072-x

Umugiraneza, O., Bansilal, S. & North, D. (2018). Exploring teachers' use of technology in teaching and learning mathematics in KwaZulu-Natal schools. Pythagoras, 39(9). DOI: 10.4102/pythagoras. v39i1.342

United States Department of Education Office of the Educational Technology. (2017). Reimagining the role of technology in education. https://tech.ed.gov/

United States Department of Education Office of the Educational Technology. (2017). Reimagining the role of technology in education. https://tech.ed.gov/

Viberg, O., Grönlund, A., & Andersson, A. (2020). Integrating digital technology in mathematics education: A Swedish case study. Interactive Learning Environments, 1- 12, https://doi.org/10.1080/10494820.2020.1770801

Von Glasersfeld, E. (1989). Cognition, construction of knowledge, and teaching. *Synthese 80*, 121–140. https://doi.org/10.1007/BF00869951

Von Glasersfeld, E. (1992) Constructivism reconstructed: A reply to suchting. *Science Education 1*, 379–384. https://doi.org/10.1007/BF00430964

Vygotsky, L. (1997). Educational Psychology. Boca Raton, FL: St. Lucie Press.

Watson, D. (2001). Pedagogy before technology: re-thinking the relationship between ICT and teaching. education and information technologies. *Education and Information Technologies, 6*(4), 251-266. 10.1023/A:1012976702296.

Wheatley, K. F. (2005). The case for reconceptualizing teacher efficacy research. Teaching and Teacher Education, 21(7), 747–766. https://doi.org/10.1016/j.tate.2005.05.009

Wright, V. & Wilson, E. (2011). Teachers' use of technology: Lessons learned from the teacher education program to the classroom. SRATE Journal, 20(2), 48-60

Wu, M., Zhao, K. & Fils-Aime, F. (2022). Response rates of online surveys in published research: A meta-analysis. computers in human behavior reports. *Computers in Human Behavior Reports, 7*. https://doi.org/10.1016/j.chbr.2022.100206

Xie, S. & Cai, J. (2020). Teachers' beliefs about mathematics, learning, teaching, students, and teachers: Perspectives from chinese high school in-service mathematics teachers. *International Journal of Science and Mathematics Education. 19*. 1-23. 10.1007/s10763-020-10074-w.

Yin, R. (2018). *Case study Research and Applications: Design and Methods* (6th ed.). Thousand Oaks, CA: Sage.

# Appendix A - Instruments



**Consent Form**

You are invited to participate in a research study about teachers' characteristics, beliefs and technology use of in-service secondary Mathematics teachers in the classroom. This study is being conducted by Marybeth Bano-Rizzo as a requirement for the degree of Doctor of Education Curriculum and Instruction at Kansas State University.
Participation in the study is voluntary. If you choose to complete this anonymous online survey, you may also opt for an optional drawing of five (5) $15 Starbucks gift cards. You have the option of doing so by providing your email address at the conclusion of the survey. Participating in this study will benefit the field of mathematics education. The electronic data will be collected anonymously through Kansas State University online survey delivery system Qualtrics. If you have any questions about this study, please contact the Principal Investigator, Dr. Sherri Martinie, at martinie@ksu.edu or 785-532-8414. By completing this survey, you are consenting to participate in this study. Please print or save a copy of this form for your records.
Consent - I agree to participate in the study described above. I have made this decision based on the information in the Consent Letter I have read.

**Items**

I agree to participate in the study described above. I have made this decision based on the information in the Consent Letter I have read.

- ○ Yes
- ○ NO

**Technology Use In The Classroom**

What is your gender?

- ○ male
- ○ female
- ○ other, please specify
- ○ prefer not to share

How old are you?

| | |
|---|---|
| Survey Questionnaire Qualtrics | Initial and Sample Follow-up Interview Questions and Protocol and Informed Consent |

## Appendix B - Write-Ups Case Study

| | |
|---|---|
| Write-Up Individual Cases | Write-Up Across Cases |

## Appendix C - Positionality Statement

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|---|
| Positionality Statement |

# Appendix D - Timeline

| Time | Activity |
|---|---|
| December 2022 | Research Proposal Defense |
| March 2023 | IRB Approval of Research Study |
| March 2023 | Distribution of Electronic Survey Questionnaire |
| March-December 2023 | Participant selection for Case study<br>Purposive sampling of participants for the case study based on the result of the quantitative survey.<br>Initial Interview |
| November -2023 | Creation of instruments for semi-structured interview based on the results from the quantitative phase |
| November-December 2023 | Semi-structured interviews<br>Qualitative Observation Field Notes<br>Video Recorded Notes |
| December 2022 | Quantitative Observation Checklist |
| January 2023 | Descriptive Statistics (Graphical, Numerical, Correlational) |
| February/March 2023 | Coding, Categorization Qualitative Data (WORD)<br>Theme Development: Calculation of Sum and averages of scores (WORD/STATA)<br>Joint Display Analysis (WORD)<br>Preliminary Theoretical Model explaining how beliefs shape the mode of technology use (Graphical Display Unit) |