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The Relationship Between Calibration, Mindset, Mathematics Anxiety and Achievement in Pre-Service Elementary Teachers

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THE RELATIONSHIP BETWEEN CALIBRATION, MINDSET, MATHEMATICS ANXIETY AND ACHIEVEMENT IN PRE-SERVICE ELEMENTARY TEACHERS

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ABSTRACT

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According to most recent studies in mathematics education, mathematics anxiety is highly prevalent in students' learning, and in fact has significant negative relationship with mathematics achievement. Thus, as educators we need to understand the factors that explain the relationship between mathematics anxiety and achievement to find any insights for increasing mathematics achievement. This dissertation explored this particular issue through constructs, calibration and mindset, and their relationship with mathematics anxiety and achievement of pre-service elementary teachers. The dissertation has three manuscripts with the first two manuscripts focusing on the relationship between calibration, mathematics anxiety and achievement, and the third manuscript focusing on mindset and its relationship with the other three constructs.

To examine these constructs in the first study, the 129 participants took mathematics anxiety and demographics surveys before their first and last exam, while they filled out self-efficacy surveys before each of their exam. For the second study, the 142 participants took mathematics anxiety and demographics surveys at the beginning and end of the semester. Additionally, self-efficacy and self-evaluation surveys were given right before and one class day or two after each exam. For the third study, the same procedure as the second study was followed with 321 participants, except a mindset

survey was given with the mathematics anxiety and demographic surveys. Copies of the exams were collected after they were graded by the instructors for all three studies.

Results of the studies revealed that calibration, mindset, and mathematics anxiety affected mathematics performance as supported by the literature where in these dissertation studies the pre-service elementary teachers have served as the population. Additionally, these four constructs are related to each other. Based on the metacognition theoretical framework and literature, the relationship seems to be that mindset may influence mathematics anxiety, calibration, and mathematics achievement while mathematics anxiety may influence calibration and mathematics achievement.

Teachers might play an important influence on the relationship between the four constructs within the pre-service elementary teachers' mathematics content courses. Given that different teachers have different styles regarding the teacher- and/or student-centered approach to teaching, of communication with the students, and of giving feedback to the students on presentations, assignments and assessments, this indicates that instructors of pre-service elementary teachers needs to be careful in their instruction methods in order to promote growth mindset, lower mathematics anxiety, and better calibration. This work also extends the methods of measuring and calculating calibration through the use of point values when measuring self-efficacy and self-evaluation instead of confidence measurements and working with open-ended questions on exams instead of multiple choice problems. Additionally, this research has implications for policy for mathematics content courses for pre-service elementary teacher population. One such implication is metacognitive habits of mind are not only important for understanding and learning mathematics but are also important for students to be life-long learners of mathematics as well as teachers of it by providing students with skills necessary for them to continually develop their thinking and understanding of the world.

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CHAPTER I

INTRODUCTION

Since the development of mathematics anxiety research in the 1950s, researchers have been exploring the relationship between mathematics anxiety and other constructs (Ashcraft & Moore, 2009). One most commonly explored construct that is connected to mathematics anxiety is mathematics achievement, where higher levels of mathematics anxiety correlate to lower mathematics achievement. The Organization for Economic Cooperation and Development (OECD, 2013) reported the results of the 2012 Program for International Student Assessment (PISA) stating that 15-year old students who reported higher levels of mathematics anxiety exhibited lower levels of mathematics performance within and across 63 of the 64 educational systems investigated. Additionally, 14% of the variation in mathematics performance was explained by the variation in mathematics anxiety, which also held when controlling gender and socioeconomic status for the highest performing students.

OECD (2013) is one of the few studies that have examined mathematics anxiety and achievement outside of North America (Foley et al., 2017). Chang and Beilock (2016) and Ramirez, Shaw and Maloney (2018) provided a review of existing studies investigating the link between mathematics anxiety and achievement in North America; in particular, focusing on factors that can cause mathematics anxiety and ways to reduce mathematics anxiety. Ramirez et al. discussed poor mathematics skills, genetic predispositions, and socioenvironmental factors (i.e., negative experience in the classroom and home experience with mathematics) as important factors that can increase mathematics anxiety and, consequently, reduce mathematics performance. Chang and Beilock also mentioned socioenvironmental factors but also expanded upon them by including some additional individual factors (cognitive, physiological, motivational).

Several of the factors discussed by Chang and Beilock (2016) and Ramirez et al. (2018) have also been found to be important influences in the connection between mathematics anxiety and achievement for pre-service elementary teachers. Factors for pre-service elementary teachers are family's mathematical history, mathematics teaching methods used by previous teachers, negative experiences in mathematics classes, and students' negative experiences with current mathematics teachers (Bekdemir, 2010; Brady & Bowd, 2005; Harper & Daane, 1998; Trujillo & Hadfield, 1999; Unglaub, 1997; Uusimaki & Nason, 2004). The examination of mathematics anxiety and achievement in pre-service elementary teachers is important because some of them will be the ones who introduce the formal mathematical environment to their students – the next generation. Additionally, teachers' mathematics anxiety can have severe consequences on the students' mathematical learning because mathematics anxiety can be transferred from teachers to students, which can result in lower mathematics performance for students (Beilock, Gunderson, Ramirez, & Levine, 2010; Gunderson, Ramirez, Levine, & Beilock, 2012; Jackson & Leffingwell, 1999).

Statement of the Problem

According to Chang and Beilock (2016),

> Given the high prevalence of mathematics anxiety and its significant negative

> relations to mathematics proficiency, understanding the factors that explain the relation between mathematics anxiety and mathematics performance may provide valuable insights for boosting mathematics achievement. (p. 33)

Herts and Beilock (2017) expand upon this call stating, "[A] considerable amount is known about how anxiety influences students' performance on tests, but far less is known about how anxiety may influence learning in the first place" which is key as "[t]his connection could have important implications in the classroom" (p. 723). Metacognitive constructs may provide insight into the relationship between mathematics anxiety and achievement; in particular, the study habits for learning that come about from students' mathematics anxiety. Legg and Locker (2009) found that certain metacognitive skills, such as planning, checking, monitoring and evaluating behaviors during a task, moderated the link between mathematics anxiety and performance. Additionally, Imbo and Vandierendonck (2007) found that high mathematically anxious students have a higher threshold to select retrieval-based strategies for problem solving, and the reduced usage of those strategies was associated with poor mathematics performance.

According to Nelson and Narens's (1990, 1994) metacognitive model, a student's strategy use does not only occur at the cognitive level but also includes metacognitive level functions and the flow of information between the two. In particular, a student must choose an appropriate strategy to solve a problem at the metacognitive level after reading and understanding the problem at the cognitive level. Then the student must take the chosen strategy to the cognitive level to attempt to solve the problem. Therefore, this could mean mathematics anxiety not only inhibits students' use of their cognitive facilities but could also inhibit their metacognitive facilities. Calibration, a metacognitive construct that utilizes the metacognitive skills discussed by Legg and Locker (2009) and the metacognitive facilities within Nelson and Narens's (1990, 1994) model, may moderate the mathematics anxiety and achievement connection.

Mindset is another construct that may influence the link between mathematics anxiety and achievement as mindset could influence how students view and utilize their mathematics anxiety to pursue or avoid mathematics, and hence, impact their mathematics achievement. Dweck (2006) defines mindset as the view people have about the malleability of their intelligence, stating that people who believe their intelligence can develop have a growth mindset, and ones who believe their intelligence is fixed have a fixed one. Mindset has been found to relate to mathematics achievement. In particular, growth mindset students tend to have better mathematics performance than fixed mindset students (e.g., Claro, Paunesku, & Dweck, 2016; McCutchen, Jones, Carbonneau, & Mueller, 2016) but, more importantly, an initial growth mindset could lead to better mathematics performance over time compared to an initial fixed mindset (Blackwell, Trzesniewski, & Dweck, 2007). However, the connection between mindset and mathematics has not been researched extensively at the tertiary level.

Dweck (2006) indicated that the view of mindset changes the meaning of failure and effort. Fixed mindset students seem more likely to use their mathematics anxiety as an indicator of a mathematical topic to avoid because the anxiety indicates they are not comfortable with the topic and might fail to understand it. Meanwhile, growth mindset students seem more likely to use their mathematics anxiety as an indicator of where they need to focus their effort to better understand the material because the challenge that comes from not being comfortable with a topic is more likely to drive them to learn the material. Fixed mindset students then are more likely to become mathematically anxious over time, while growth mindset students are more likely to become less mathematically anxious. This claim is supported by Dweck (2006) and Yeager and Dweck (2012) who found growth mindset creates resilience in the face of setback, and Johnston-Wilder, Lee, Brindley and Garton (2015) who found mathematical resilience leads to a decrease in mathematics anxiety.

Besides examining constructs that could influence the connection between mathematics anxiety and achievement, the population investigated is also important. One such vital population is pre-service elementary teachers as some of them will be the ones who introduce the formal mathematics and mathematical thinking to the pupils. Additionally, mathematics anxiety in pre-service elementary teachers is more common and prevalent than in other undergraduate populations (Baloglu & Kocak, 2006; Bessant, 1995; Hembree, 1990; Kelly & Tomhave, 1985; Novak & Tassell, 2017). This anxiety can have severe consequences on the students' mathematical learning; for example, teachers' mathematics anxiety can be transferred to their students, resulting in lower mathematics performance in students (Beilock et al., 2010; Gunderson et al., 2012; Jackson & Leffingwell, 1999). Similar to the mathematics anxiety and achievement research previously mentioned, this relationship also holds for pre-service elementary teachers (e.g., Hembree, 1990). Moreover, mathematics content courses that pre-service elementary teachers take for their degrees could help reduce mathematics anxiety (Alsup, 2005; Tooke & Lindstrom, 1998).

Given the possible influence of mindset on the link between mathematics anxiety and achievement and the other positive effects of growth mindset (e.g., increased mastery learning over performance learning, increased mathematical resilience, more willing to work on challenging problems) on students' learning, growth mindset needs to be promoted within the mathematics classroom, especially for pre-service teachers (Boaler, 2016; Dweck, 2006). This would allow them to go through the experience of developing a growth mindset that could be utilized in their future teaching. Also, this would help avoid the development of false growth mindset (Dweck, 2015) wherein teachers say they promote growth mindset in the classroom but their actions and discourse prove otherwise. Mathematics teachers and education researchers need to know more about how constructs, such as mindset, relate to pre-service elementary teachers' mathematics anxiety and achievement.

Purpose and Research Questions

Following Chang and Beilock's (2016) and Herts and Beilock (2017) call for factors that could influence and possibly explain the link between mathematics anxiety and achievement, the purpose of this dissertation is to investigate how mindset and the metacognitive construct of calibration relates to mathematics anxiety and achievement. I focused on the pre-service elementary teacher population given their importance for future students' mathematical learning. Given the call for metacognition in the classroom (Carroll, 2008), and in particular, calibration in the classroom (Hacker, Bol, & Keener, 2008b), the following research questions guide this investigation within the mathematics classroom:

Q1 What is the statistical relationship between calibration and mindset for pre-service elementary teachers?

Q1a Is there a statistically significant difference in calibration over time for pre-service elementary teachers who demonstrate a fixed and those who demonstrate a growth mindset throughout the semester accounting for instructor and semester?

Q2 What is the statistical relationship between calibration and mathematics anxiety for pre-service elementary teachers?

Q2a Is the change in mathematics anxiety of underconfident pre-service elementary teachers statistically significantly different from the change in mathematics anxiety of overconfident teachers accounting for instructor?

Q3 What is the statistical relationship between calibration and mathematics achievement for pre-service elementary teachers?

Q3a Does calibration statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q4 What is the statistical relationship between mindset and mathematics anxiety for pre-service elementary teachers?

Q4a Is there a statistically significant difference in mindset between low, moderate and high math anxious pre-service elementary teachers at the beginning and end of the semester accounting for instructor and semester?

Q5 What is the statistical relationship between mindset and mathematics achievement for pre-service elementary teachers?

Q5a Is there a statistically significant difference in the change in mindset for students of different achievement levels accounting for instructor and semester?

Q6 What is the statistical relationship between mathematics anxiety and mathematics achievement for pre-service elementary teachers?

Q6a Does the change in mathematics anxiety statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q7 Does calibration, mindset, and mathematics anxiety predict mathematics achievement for pre-service elementary teachers?

Q7a Does calibration and mathematics anxiety statistically significantly predict mathematics exam performance in pre-service elementary teachers accounting for instructors?

Q7b Does calibration and mathematics anxiety predict final exam performance accounting for instructor?

Q7c Does mindset, calibration and mathematics anxiety predict mathematics exam performance in pre-service elementary teachers accounting for semester and instructor?

These questions were addressed through three quantitative studies. All the participants were pre-service elementary teachers taking a mathematics content course (first or third course) within a required three-course sequence at a mid-size university in the Rocky Mountain Region of the United States. Even though these courses are primarily for elementary education students, some students majoring in special education and early childhood education also required to take the courses. Students met twice a week for 75 minutes over a 15-week semester and spent most of their class time working in groups. The first course centered on the real number system and arithmetic operations with a focus on the structure and subsets of real numbers using patterns, relationships, and properties. The third course emphasized development of spatial reasoning in geometry and measurement with a focus on two- and three-dimensional shapes along with their properties, measurements, constructions and transformations. In the outline of dissertation sections that follows the literature review, I expand upon each study that I conducted to address these research questions and manuscripts I wrote.

In this chapter, I first share a literature review of research studies on calibration, mathematics anxiety, and mindset and their link to each other and achievement. Following this discussion, I revisit the research questions that guided each study in stand-alone manuscripts in Chapters II, III, and IV, and provide the structure of the dissertation. I end this chapter with a discussion of the significance of the dissertation.

Literature Review

In this section, I provide a review of the literature on previous research studies that focused on calibration, mindset, mathematics anxiety, and pre-service elementary teachers' learning along with additional constructs (e.g., self-efficacy, test anxiety, self-regulation) related to those areas. In particular, studies on metacognitive theory pertaining to calibration, the ways of measuring calibration, and the relationship between calibration and achievement are presented first in this chapter. Then, mathematics anxiety and its relationship with achievement, self-efficacy, self-regulation and calibration are summarized from existing studies. This is followed by a review of mindset literature connecting to mathematics achievement, anxiety, and calibration. Lastly, studies on pre-service elementary teachers related to mathematics anxiety, self-regulation, self-efficacy, calibration, and mindset are examined.

Metacognition and Calibration

Researchers have been emphasizing the importance of metacognition in learning in general and in domain-specific areas such as mathematics (Kramarski & Mevarech, 2003; Schoenfeld, 1983; Veenman, Van Hout-Wolters, & Afflerbach, 2006) in particular. Research studies exist on metacognition and learning but a sparse amount of them have focused on mathematics education at the undergraduate level. In addition, Nelson and Narens (1994) pointed out metacognition research studies lack cumulative progress, which is partly due to researchers attempting to control variations in participants' cognition in laboratory settings. Hacker et al. (2008b) argued there is a need for researchers "to go outside the laboratory into more ecologically valid environmental situations" (p. 429) such as classrooms.

To address this particular concern of studying metacognition outside the laboratory setting and contribute to the progress of metacognition research, Hacker et al. (2008b) expanded Nelson and Narens's (1994) ideas to study calibration – one of the constructs of metacognition. They adopted the idea of environmental situation to mean the classroom setting. In particular, they noticed the need to study students' calibration in the classroom because calibration for studying and taking exams in a classroom setting is different than in a laboratory study due to the underlying motivations students possess by taking a particular course. Calibration is related to students' test-taking and study habits and these habits can be defined through metacognitive constructs. Before defining these metacognitive constructs, we need to examine some existing definitions and models of metacognition to better understand its constructs and their relationships.

Metacognition has several different models and different constructs correspond to those models. Flavell's (1979) work on metacognition formed the basis for most of these models. Stolp and Zabrucky (2009) discussed two common dimensions of Flavell's model of metacognition that appear within other metacognition models, namely, metacognitive knowledge and metacognitive experience. Metacognitive knowledge is general knowledge people have about their own and others' cognitive processes. In particular, metacognitive knowledge consists of knowledge and beliefs about what factors affect cognition and the ways these factors interact to affect cognition (Flavell, 1979). The types of factors that influence people's cognitive processes are described under three categories: person, task, and strategy. The person category consists of everything a person believes about his/her and other people's nature as cognitive processors. The task category involves information available to an individual when this person is thinking about a task. The strategy category contains knowledge of strategies a person might utilize for a cognitive undertaking. According to Flavell, metacognitive knowledge concerns interactions among two or three of these categories.

On the other hand, metacognitive experiences include processes of evaluating and regulating a person's ongoing cognition. For example, when students are asked if they understand why they just did a particular step to solve a problem, they are evaluating their understanding and attempting to regulate their ongoing cognition. These two dimensions of metacognition are interconnected as metacognitive knowledge can lead to metacognitive experiences.

One reason metacognitive knowledge can lead to the development of metacognitive experience is students' need to appropriately identify the extent of their understanding and use the best strategies to develop comprehension. If a student attempts to identify and address gaps in comprehension, then the student potentially changes his/her knowledge and modifies metacognitive knowledge accordingly. For example, strategies students could use include spending more time studying a topic or talking to the instructor to get some guidance on solving a problem. However, if a student does not attempt to address such gaps in comprehension, then metacognitive experience does not necessarily lead to a change in metacognitive knowledge.

Nelson and Narens (1990) utilized these two dimensions to create a theoretical framework for metacognition. According to Hacker et al. (2008b), this framework is based on three principles:

> (1) Mental processes are split into an object-level (i.e., cognition) and a meta-level (i.e., metacognition); (2) the meta-level contains a dynamic model of the

> object-level, which is the source of metacognitive knowledge or understanding of the object-level; and (3) there are two processes corresponding to the flow of information from the object-level to the meta-level (i.e., monitoring) and from the meta-level to the object-level (i.e., control). (p. 432)

From this perspective, metacognition is defined as the monitoring and control of the object-level of thought by the meta-level. Metacognitive monitoring allows people to obtain information from the metacognitive level about their knowledge and strategies at the cognitive level while control allows people to use their metacognitive knowledge (i.e., knowledge from the metacognitive level) to regulate their thoughts at the cognitive level. Van Overschelde's (2008) diagram that describes the relationship between the cognitive and metacognitive levels and the role of metacognitive monitoring and control is shared in Figure 1.1.

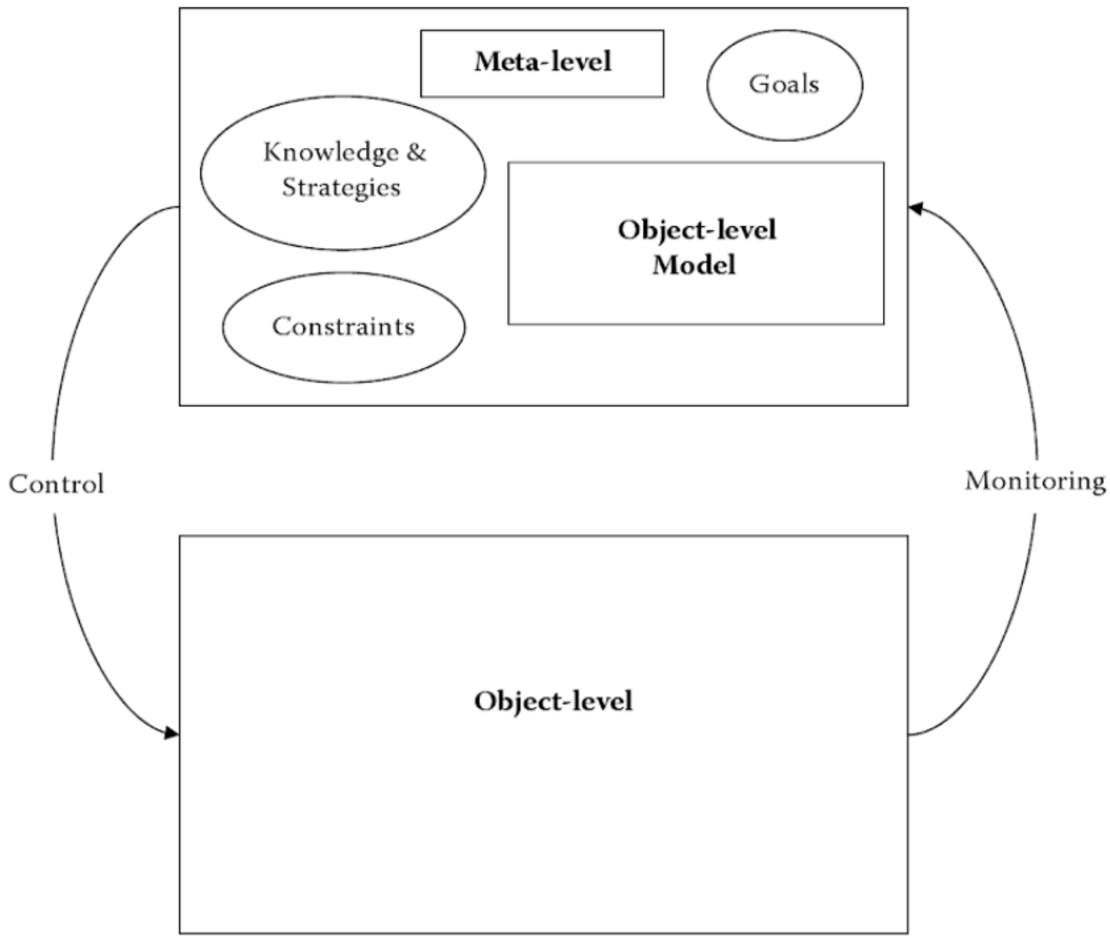

Figure 1.1. Van Overschelde's metacognitive model (p. 48).

Within the metacognitive model, *calibration* plays an important part, acting as one of the tools students can use during evaluating and regulating their studying. Calibration is defined as the measure of a person's perceived performance on a task compared to the actual performance on that task (Hacker et al., 2008b; Nietfeld, Cao, & Osborne, 2006). *Calibration accuracy* (or *calibration prediction*) is the accuracy of a person's self-efficacy beliefs (Chen, 2006; Pajares & Miller, 1997) while *calibration postdiction* is the accuracy of a person's self-evaluation beliefs. In other words, if perceived performance judgment is made before the actual performance, then calibration accuracy is measured; while if the judgment is made after the actual performance, then calibration postdiction is measured. *Self-efficacy* is the extent of one's belief in one's own ability to complete tasks and reach goals (Bandura, 1997) and "determine[s] the goals people set for themselves, how much effort they expend, how long they persevere in the face of difficulties, and their resilience to failures" (Bandura, 1995, p. 8). *Self-evaluation* is the extent of one's belief in one's own ability on completed tasks. Other synonyms of calibration are calibration of comprehension, calibration of confidence, calibration of judgments, and calibration of performance. Other synonyms of calibration accuracy and calibration postdiction are calibration prediction and calibration of self-evaluation, respectively.

The underlying psychological process shown in calibration accuracy "entails a person's monitoring of what he or she knows about a specified topic or skill and judging the extent of that knowledge in comparison to some criterion task such as examination" (Hacker et al., 2008b, p. 432). For example, while studying for an upcoming mathematics exam in college algebra, students monitor what they know and decide whether or not they need to study more to pass the test. Students usually go through this process throughout their studying to determine whether they have studied enough to reach their goal for the test, which could be to pass with a 70% or to get an A. As students study, they also determine if certain topics within their study materials have been sufficiently studied by examining their confidence on those topics. The change in confidence at the meta-level affects the object-level by changing students' focus of what they study or should study. If students feel confident on a particular topic, they will typically move on to other topics about which they feel less confident; while if students feel underconfident on a particular topic, they will typically spend more time studying that topic. Hacker et al. (2008b) explained a couple of consequences of overconfidence and underconfidence for students in reading:

> On the one hand, strong overconfidence during reading could fail to trigger appropriate control processes necessary for students to attain greater comprehension of the text. On the other hand, strong underconfidence could cause students to misallocate precious study time to continue reading in the hopes of further comprehending the text when in fact their comprehension may be more than sufficient for the task. (p. 432)

Even though this quote pertains to reading, a similar idea could be applied to learning mathematics. Overconfidence, underconfidence, and inaccurate judgments of one’s capabilities can harm one’s learning and motivation in mathematics (Ramdass & Zimmerman, 2008). To be overconfident or underconfident in one's ability for a particular task is referred to as calibration bias. The theoretical relationship between calibration and learning is described as inverse variation between learning and calibration bias and direct variation between learning and calibration accuracy. The inverse variation between learning and calibration bias is due to students’ under- or overconfidence, leading them to focus too much or too little on a topic, respectively; thus, students do not allot their time in the most efficient manner when studying, which in turn leads to students possibly not knowing all the material they need to succeed on an assessment. The direct variation between learning and calibration accuracy is due to the fact that students who are better calibrated have a better idea of what they know well and not so well. This leads them to focus on the material they are struggling with, which in turn should allow students to do well on an assessment.

Calibration measurement. Calibration has been measured in different ways in research and does not have a set measurement method (Alexander, 2013; Dinsmore & Parkinson, 2013; Hacker et al., 2008b). Hacker et al. (2008b) summarized some of these methods by examining four key questions to consider when measuring calibration: "(1) What kind of judgment is being made? (2) What level of performance is being judged? (3) When is the judgment being made? (4) How is the difference between judged and actual performance calculated?" (p. 435).

To answer the first question, the type of judgment made is a likelihood or confidence judgment where participants determine how likely or confident they are to complete a particular task or a group of tasks. This judgment can be made by using a Likert scale such as a likelihood scale or confidence scale where a person is restricted to six categories of 0%, 20%, 40%, 60%, 80%, and 100%, or having a continuous line with values between 0% and 100%. Also, judgments can be obtained by asking participants how many of the total questions they will get correct. These measures are the most common in an education setting. However, another common measurement used in monitoring literature is dichotomous judgments where an item is determined to be correct or incorrect (Schraw, Kuch, & Gutierrez, 2013). Another relatively new way of measuring confidence judgments is using a magnitude scale. This method has a student determining how confident he/she is for that item compared to a base item for each item on an assessment (Dinsmore & Parkinson, 2013).

For the second question, performance can be measured at a local or global level. The local level has participants make judgments on each item on a test. The global level has participants make a judgment of the test as a whole. For example, researchers could ask participants to determine if they will get each item on the test correct or wrong and then ask them how many items they expect to get correct out of the total number of questions. The former situation is at the local level while the latter is at the global level.

For the third question, calibration can be determined using judgments made before or after a test. The comparison of judgments made before a test (predicted performance) and the actual performance on the test are referred to as calibration of comprehension, calibration prediction, or calibration accuracy where the last one is the most common term. Meanwhile, the comparison of judgments made after a test (postdicted performance) and the actual performance is referred to as calibration of self-evaluation or calibration postdiction. Hacker et al. (2008b) described the difference between calibration prediction and postdiction using Nelson and Narens's (1994) model of acquisition, retention, and retrieval for metacognitive monitoring. The prediction occurs after acquisition and retention but before retrieval, while postdiction occurs after retrieval. For example, when students need to solve a problem, they need to read the problem and understand what is asked. Then students can judge how well they will do (prediction) based on that information. After understanding what the question is asking, students will attempt to retrieve any relevant information they think will help solve the problem. Using that information, students will solve the problem to the best of their ability. Then they can estimate how well they did (postdiction) on the problem.

For the fourth question, researchers must consider their answers to the other three questions, which are determined typically by the amount of access researchers have to the participants. Hacker et al. (2008b) considered taking the absolute value of the difference between judged and actual performance at the global level as the most straightforward measure of calibration. This method could also be done at the local level. At the local level, actual performance is assessed with a 0-point for incorrect items or a 1-point for correct items. Then the calibration is calculated by taking the absolute difference between the judged performance and the actual performance for each item. The difference for each item is then summed and divided by the total number of items. In either case of the local and global levels, the closer the value is to zero, the more calibrated the individual. By dropping the absolute value when calculating accuracy or postdiction, the value produced is a calibration bias score. Another equivalent way to calculate calibration bias for the local level is to subtract the mean performance score from the mean judgment score, which is how Champion (2010) conceptualized calibration bias.

In addition, there are other measurement models for calibration. For example, Boekaerts and Rozendaal (2010) studied the effects of gender, type of mathematical problem, instruction method, and time of measurement on calibration of fifth graders in two different mathematics instruction programs, the gradual program design and realistic program design. They measured calibration using the concordance index (C-index), the O/U-index and the Aggregate Nutrient Density Index (ANDI). The C-index measures a student's skill for accurate calibration. The O/U-index measures a student's tendency to be over- or underconfident. The ANDI measures a student's skill to discriminate between whether an event occurs or not. The confidence scale used to calculate the indexes is a dichotomous scale of confident or not confident and was used before and after the assessment.

Dinsmore and Parkinson (2013) investigated whether or not the rho coefficient could provide valid inferences for calibration, whether different types of scales used for confidence judgments affected the distribution of calibration scores, and which factors participants reported using when making confidence judgments. They had 72 students from a human development research methods course read two passages and answer multiple-choice questions about the passages. After answering each question, students needed to determine their confidence for their answer. On one passage, students had to identify their confidence using a 100-mm scale; on the other, they used a magnitude scale. With the scales and the questions, calibration was calculated using the rho coefficient. They also created scatter plots for each participant and each confidence judgment measurement. The plots had the actual performance on the y-axis and the rho coefficient on the x-axis.

A calibration graph (Keren, 1991; Yates, 1990) is another method for measuring calibration. Actual performance is plotted on the y-axis and predicted and/or postdicted performance is plotted on the x-axis. The line $y = x$ on the graph represents perfect calibration (i.e., actual performance is exactly the same as the predicted/postdicted performance). Points above the line indicate underconfidence while points below the line indicate overconfidence. Even though this particular method was connected to the absolute value method described above, calibration graphs are more interpretable in terms of patterns with respect to calibration across performance levels and the ways overconfidence and underconfidence vary with performance (Weingardt, Leonesio, & Loftus, 1994). This was very similar to the scatter plots used by Dinsmore and Parkinson (2013) except the values on the x-axis were different. Also, the scatter plots provided the researchers with a visualization of how confidence and performance related, which is exactly what calibration graphs do.

Another study used different combinations of the type of scale used for judgment, the level of performance being judged, when the judgments are made, and how calibration is calculated. Nietfeld, Cao, and Osborne (2005) examined the effect of practicing metacognitive monitoring on tests on calibration and calibration bias, and whether global monitoring was more accurate than local monitoring. They had 27 undergraduates in an educational psychology survey course and provided a calibration postdiction for each exam. The postdiction consisted of a local judgment (i.e., judgment for each item) and a global judgment (i.e., judgment for the entire test). For both types of judgment, students rated their confidence on a 100-millimeter scale. Using the postdiction survey and the exam scores, calibration scores were calculated at the local level by taking the absolute difference between the confidence judgment and the actual performance for each item. The difference for each item was then summed and divided by the total number of items. Global calibration was calculated by taking the absolute value of the difference between the global confidence judgment and actual performance. Calibration bias was calculated by subtracting the mean performance score from the mean judgment score.

Given the options above to measure calibration, this dissertation examined calibration at the local and global levels. In particular, students were given point values of a problem on an exam and asked to determine how many points they would get on it before doing the problem for the local level. For the global level, students were given the point value of the exam and asked to determine how many points they would get on it before doing the problems on the exam. Using these estimations along with students' actual scores, Hacker et al.'s (2008b) method of calculating local and global calibration was utilized throughout the studies in this dissertation.

Calibration and achievement. Achievement research has been a main focus in mathematics education due to noticeable differences among genders, socioeconomic status (SES), and races, and U.S. students' poor performance on national and international tests. Researchers have examined mathematics achievement at many different levels by using test achievement, quiz achievement, course grade, and sometimes grade point average (GPA). The main mathematics achievement variable has been test achievement especially in studies involving the Trends in International Mathematics and Science Study (TIMSS; Fryer & Levitt, 2010; Kaiser & Steisel, 2000). Studies utilizing the TIMSS and other achievement research have examined the difference among genders, SES, and races (Ercikan, McCreith, & Lapointe, 2005; Fryer & Levitt, 2010; Kaiser & Steisel, 2000; Lubienski, 2002; McGraw, Lubienski, & Strutchens, 2006). Besides these studies, research has been done to determine the effects of parents' beliefs and attitudes, teachers' beliefs, teachers' mathematics anxiety, instruction practice, pedagogical content knowledge and content knowledge, and other psychological constructs such as motivation and attitudes on student mathematics achievement (Beilock et al., 2010; Gales & Yan, 2001; Hill, Rowan, & Ball, 2005; Lockwood et al., 2007; Schreiber, 2002; Tiedemann, 2000). This pair of constructs provided insight in this dissertation when addressing the third and seventh research questions.

One construct related to achievement that has not been examined extensively in mathematics education is calibration. One of the first studies in mathematics that looked at calibration of comprehension was conducted by Pajares and Miller (1994). The researchers examined the role of self-efficacy beliefs in mathematical problem solving in 350 undergraduates. Students were given the Mathematics Confidence Scale (MCS; Dowling, 1978), which is a 5-point Likert scale, and the Mathematics Problem Performance Scale (Dowling, 1978), which is a multiple-choice assessment. Pajares and Miller defined overconfidence as marking a four or five on the MCS and then getting the problem wrong on the assessment; underconfidence was defined as marking a one or two on the MCS and then getting the problem correct on the assessment. A response of three on the MCS was not included in the determination of under- and overconfidence. They found only 25 of the 350 students predicted their response to all 18 questions on the assessment, 57% of the students overestimated their performance, and 20% underestimated their performance. Pajares (1996) continued this line of inquiry in other studies (Pajares & Kranzler, 1995; Pajares & Miller, 1997).

Pajares and Kranzler (1995) examined the influence of mathematics self-efficacy and mental ability on mathematics problem-solving performance of 329 high school geometry students. Students were given the MCS (Dowling, 1978), which was expanded by the researchers to a 6-point Likert scale along with the Mathematics Problem Performance Scale (Dowling, 1978). The researchers defined overconfidence as marking a four, five, or six on the MCS and then getting the problem wrong on the assessment; underconfidence was defined as marking a one, two, or three on the MCS and then getting the problem correct on the assessment. They noticed 86% of the participants were overestimating their performance while 9% were underestimating their performance. Additionally, the underconfident group was better calibrated than the overconfident group.

Pajares (1996) examined the predictive and mediational role self-efficacy played in mathematics problem solving in regular and gifted eighth graders using path analysis. He found gifted students had better achievement and calibration accuracy than regular students as regular students tended to overestimate and underestimate their performance by a greater average number of problems. Also, girls and boys had no significant difference in their calibration accuracy scores and calibration bias except gifted girls had significantly lower calibration accuracy scores than the gifted boys. Some other differences were that overall girls had better calibration accuracy scores, had lower bias, and were overconfident on fewer items than the boys; however, none of these differences was statistically significant. Some researchers (e.g., Boekaerts & Rozendaal, 2010; Erickson & Heit, 2013; Sheldrake, Mujtaba, & Reiss, 2014) also found differences between genders with respect to under- and overconfidence while other researchers (e.g., Chen, 2003; Chen & Zimmerman, 2007; Desoete & Roeyers, 2006; Ozsoy, 2012; Pajares & Graham, 1999) found no differences.

Pajares and Miller (1997) continued the examination of eighth graders but investigated the influence of the type of assessment on self-efficacy judgments and calibration accuracy along with the difference between 327 algebra and pre-algebra students on those measures. The experiment had two treatments—the types of assessment (open-ended or multiple-choice questions) and the types of self-efficacy judgment questions (judgments for open-ended assessment or judgments for multiple-choice assessment), which totaled four groups for comparison. The researchers used a 6-point Likert scale for both types of self-efficacy judgments that ranged from one (*No confidence at all*) to six (*Complete confidence*) to rate students' confidence in solving each problem. The researchers found the type of self-efficacy judgment questions did not make a difference in students' calibration but type of assessment did. Students who took the multiple-choice assessment significantly outperformed those who took the open-ended assessment, which resulted in the open-ended assessment groups having greater overconfidence and less calibration accuracy. Also, algebra students had higher performance and better calibration than did pre-algebra students. This was one of the first indications in mathematics that achievement and calibration are positively correlated in mathematics. Other mathematics education researchers (Chen, 2003; Chen & Zimmerman, 2007; Garcia, Rodriguez, Gonzalez-Castro, Gonzalez-Pienda, & Torrance, 2016; Ozsoy, 2012) found similar results.

Other mathematics education researchers have attempted to gain a better understanding of calibration in mathematics by examining students' calibration longitudinally and by investigating what constructs might influence calibration. Sheldrake et al. (2014) observed calibration of mathematics self-evaluations (i.e., calibration postdiction) in 2,490 students from England for Years Eight and 10. They found students' calibration postdiction decreased from Year Eight to 10 but was slightly more overconfident at Year Eight compared to Year 10. Also, students with accurate calibration postdiction at Year 10 reported the highest intention to study mathematics at Year 12 and 13, which is not required in England, along with providing the highest self-reports for task-level enjoyment, ease, interest, and subject-level self-concept for mathematics. This hinted at the potential that pre-service elementary teachers with accurate calibration postdiction would be more willing to include mathematical experiences in their learning and teaching. Moreover, they would potentially focus more on mathematical activities in their classrooms for their future students.

Rinne and Mazzocco (2014) conducted a developmental, longitudinal study of the relationship between students' calibration of mental arithmetic judgments and their performance on a mental arithmetic task. The participants completed a problem verification task every year from fifth to eighth grade where they had to judge the accuracy of arithmetic expressions and rate their confidence for each judgment. Results showed calibration postdiction was strongly correlated to mental arithmetic performance and continued to develop even as mental arithmetic accuracy started to cap out. Another result was better calibration postdictions in fifth grade predicted larger gains in mental arithmetic accuracy between fifth and eighth grades. These findings seemed to indicate that when students started to develop a higher level of understanding of a topic, they continued to develop their metacognition, probably due to the development of their metacognitive experiences. Also, students with more accurate calibration postdictions on a topic could gain a better understanding of the topic in the future. In other words, better calibrated students could be using more of their metacognitive processes to deepen their understanding of a topic instead of using those processes to determine what they did and did not understand.

Desoete and Roeyers (2006) investigated the role of evaluation (global and local calibration scores) in mathematics for second, third and fourth graders. They found overall calibration had a small, but significant relationship with mathematics performance. Also, older students were more accurate with their calibration scores than were younger students. This seemed to indicate the age of the students might impact calibration and to a larger scale a student's metacognitive knowledge.

As discussed earlier in Boekaerts and Rozendaal's (2010) study with fifth graders, students overestimated their performance on application problems more than on computation problems, while they were better at predicting the variability of their performance on computations. Also, students were more overconfident in their performance after solving the problem than before with the exception of the C-index of the computation problems in which the students were better calibrated after solving the problems. This finding was opposite of what other researchers found for the relationship between calibration bias for predictions and postdictions but the contradicting results might have been due to the different subject areas on which these studies focused (e.g., Bol & Hacker, 2001; Bol, Hacker, O'Shea, & Allen, 2005) and the different populations studied where most of the other studies had high school and college students as participants (Hacker et al., 2008b).

Labuhn, Zimmerman, and Hasselhorn (2010) investigated the effects of self-evaluative standards (mastery learning vs. social comparison vs. no standard) and types of graphed feedback (individual vs. social comparison vs. no feedback) on calibration and mathematics performance for fifth graders and at-risk fifth graders. The findings demonstrated that calibration accuracy and postdiction positively correlated with performance while calibration accuracy and postdiction biases had a strong negative correlation. Calibration postdiction was more accurate for those who received feedback compared to those who did not while feedback increased calibration accuracy in overconfident students. The influence of feedback on calibration from this study contradicted a finding by Schraw, Potenza and Nebelsick-Gullet (1993) and Nietfeld et al. (2005) in which feedback did not affect calibration. However, Nietfeld et al. (2006) found feedback with calibration accuracy practice on weekly quizzes improved calibration accuracy. Also, Hacker, Bol, Horgan, and Rakow (2000) reported feedback only benefited high achieving students when the feedback was provided over several tests. These findings indicated not all feedback would lead to better calibration but certain types of feedback such as students knowing their calibration scores and biases and explanations of the problem solutions and why students answer were incorrect might make a difference.

Additionally, Schraw et al. (1993) found item difficulty did not affect calibration. However, Chen (2003), Chen and Zimmerman (2007), Rinne and Mazzocco (2014), and Stankov, Lee, Luo, and Hogan (2012) established that item difficulty affected calibration. Chen and Chen and Zimmerman noticed students became less accurate in their calibration as item difficulty increased. Rinne and Mazzocco found the "hard-easy" effect (i.e., overconfident on hard questions but well-calibrated or sometimes underconfident on easy problems) appeared for the students. Stankov et al. (2012) noted students were overconfident on difficult items, underconfident on easy items, overconfident on medium difficulty items for low ability students, and good calibration or slightly underconfident for high ability students. The difference in findings could relate to the difference in age and cultures as Chen and Zimmerman and Stankov et al. examined sixth graders and 15-year old Chinese students in their studies while Schraw et al. and Chen utilized American undergraduates and seventh graders, respectively.

Besides examining item difficulty's effect on calibration, Chen (2003) conducted a path analysis on calibration and other possibly related constructs. Calibration accuracy had both positive direct and negative indirect effects on mathematics performance. The negative indirect effect was mediated through self-efficacy beliefs, which had a positive effect on performance. In other words, an increase in calibration accuracy led to a decrease in self-efficacy that, in turn, led to a decrease in mathematics performance. Overall, calibration accuracy had a positive effect on mathematics performance. Also, prior mathematics achievement had an indirect effect on mathematics performance when calibration was a mediating variable. This meant higher prior mathematics achievement led to an increase in calibration accuracy, which led to an increase in current mathematics performance.

The relationship between calibration and achievement is complicated as observed in the aforementioned studies but, overall, the literature indicates calibration has a positive influence on mathematics achievement. Other constructs play different roles and affect the relationship. Two important constructs that come from the metacognitive view of calibration are self-efficacy and self-regulation. Self-efficacy is important due to some researchers defining calibration accuracy as the accuracy of self-efficacy. Additionally, the dissertation studies utilized this version of the definition of calibration accuracy. Also, calibration accuracy can be calculated by using self-efficacy judgments. However, not many researchers have examined the relationship between calibration and self-efficacy. Chen (2003) and Chen and Zimmerman (2007) have examined this relationship. Chen found calibration accuracy and self-efficacy were not significantly correlated, which was the opposite of what Chen and Zimmerman found, but this might be due to differences in calibration accuracy measurement and the fact that Chen's path analysis indicated direct effects of calibration accuracy on self-efficacy.

Self-regulation is another important construct to examine with regard to calibration. Self-regulation refers to the processes individuals use to activate and maintain their thoughts, behaviors, and emotions to achieve learning goals (Ramdass & Zimmerman, 2008). Self-regulation is important because students should be checking their calibration as they study, which in turn should lead to students self-regulating their learning processes to help themselves succeed in an upcoming assessment. Also, within the last 15 years or so, a self-regulated learning theory has appeared within calibration research wherein researchers focused more on the possible effects of calibration on self-regulated learning or self-regulated learning on calibration. However, only a few researchers have examined the relationship between calibration and self-regulation quantitatively. Ramdass and Zimmerman (2008) and Zimmerman, Moylan, Hudesman, White, and Flugman (2011) examined the effects of self-regulated learning instruction of mathematics on calibration for fifth and sixth graders and undergraduates, respectively. In both studies, self-regulated learning instruction led to better calibration. Thiede, Anderson, and Therriault (2003) found different methods of self-regulation led to different levels of calibration, which in turn led to different levels of effective self-regulation in reading comprehension of undergraduates.

With all these reviewed mathematics education research studies examining the relationship between calibration and achievement along with possible constructs that could influence the relationship, one issue arose. All described mathematics calibration studies examining the relationship between calibration and mathematics achievement had aspects of laboratory studies rather than aspects of "ecologically valid environmental situations" (Hacker et al., 2008b, p. 429). Even though participating students were from certain classrooms, the way the researchers measured the correctness of the items on the assessments did not align with how mathematics instructors would authentically grade problems unless the assessment was a multiple-choice exam. In other words, researchers graded problems as correct or incorrect. This aspect of calibration research is important given that national and international exams utilize multiple-choice questions. However, a lot of assessments given by teachers in the classroom and for homework tend to consist of questions that require students show their work and students are assigned partial credit to their work. Also, Hacker et al. (2008b) mentioned that examining calibration in the classroom is one important place where calibration research is lacking. This dissertation examined calibration of comprehension for questions where students were required to show work (also called open-ended questions) in classroom settings.

As the purpose of this study was to explore calibration of pre-service elementary teachers and any possible relationship between anxiety and calibration, I summarized mathematics anxiety research for any connections to calibration by examining mathematics achievement, self-regulated learning, and self-efficacy in the following sections.

Research Studies in Mathematics Anxiety

Over the last few decades, mathematics anxiety research has become a larger part of mathematics education research due to reported negative consequences of mathematics anxiety on students' learning and achievement. For this reason, education researchers have attempted to better understand mathematics anxiety and its possible connections to other constructs that affect students' learning and performance.

In a seminal article for mathematics anxiety, Hembree (1990) conducted a meta-analysis of 151 mathematics anxiety studies. He reviewed the results of these studies to determine the connection of mathematics anxiety to psychological constructs, mathematics anxiety of different populations of students, and treatment methods that have been attempted to decrease mathematics anxiety. Hembree found mathematics anxiety was directly related to poor performance on mathematics tests and avoidance of mathematics and inversely related to positive attitudes toward mathematics. Also, females displayed higher levels of mathematics anxiety than did males. Some educational researchers have continued to examine mathematics anxiety's connection to psychological constructs such as test anxiety, mathematics achievement, mathematics self-efficacy, and mathematics self-regulation. I examined the literature of each of these topics in relation to mathematics anxiety along with any mathematics anxiety studies that examined calibration.

Mathematics anxiety and test anxiety. Test anxiety is another type of anxiety that has and continues to be researched in education due to its negative effects on students. In mathematics classrooms, test anxiety has been examined but not as much as mathematics anxiety. Lilley, Oberle, and Thompson (2014) defined test anxiety as a subset of state anxiety where state anxiety is a severe reaction to a certain situation that appears intimidating, which then induces stress on an individual. In particular, test anxiety comes from being in a testing situation (Lilley et al., 2014). Using this definition or a similar definition of test anxiety, a few researchers have examined test anxiety in the mathematics classroom. However, within this definition, a particular issue has not been addressed: it is not clear if researchers considered mathematics anxiety a subset of test anxiety or its own separate construct when discussing test anxiety in the domain of mathematics.

This is an important distinction for mathematics anxiety and test anxiety due to the relationship between the two could determine how researchers investigate these two anxieties in mathematics education and the resulting impact of their findings. Unfortunately, there is no clear answer to the relationship from a theoretical viewpoint. Richardson and Woolfolk (1980), Stöber and Pekrun (2004), and Stankov (2010) assumed mathematics anxiety was a subtype of test anxiety while Ashcraft and Ridley (2005) viewed the two constructs as separate but related. A few researchers have examined the relationship between the two empirically through correlational and variance analyses of different mathematics anxiety and test anxiety surveys.

One of the earliest research studies that examined the relationship between mathematics and test anxiety was conducted by Betz (1978). Betz examined factors that could relate to mathematics anxiety. Using a revised version of the Mathematics Anxiety Scale (Fennema & Sherman, 1976) for college students and the Test Anxiety Inventory (Spielberger, Lushene, & McAdoo, 1977), the researcher found mathematics anxiety and test anxiety were significantly and positively correlated at a moderate level. Hunsley (1987) found similar results between the two anxieties but used the Debilitating Anxiety scale of Anxiety Achievement Test (Alpert & Haber, 1960) and the Mathematics Anxiety Rating Scale (Richardson & Suinn, 1972) to measure test anxiety and mathematics anxiety, respectively. Over the years, other researchers have explored the relationship between the two anxieties in different ways and a couple of them have attempted to determine if the two anxieties are separate constructs.

Rounds and Hendel (1980) explored the dimensionality of the Mathematics Anxiety Rating Scale (Richardson & Suinn, 1972). To help with this exploration, the researchers measured test anxiety using the Suinn Test Anxiety Behavior Scale (Suinn, 1969). They found the scale had two factors/subscales, mathematics test anxiety and numerical anxiety. Besides finding mathematics anxiety and test anxiety were significantly, positively, and moderately correlated, they determined test anxiety was significantly and positively correlated to both subscales. The mathematics test anxiety scale was highly correlated to test anxiety while the numerical anxiety scale was moderately correlated. Zettle and Raines (2000) and Devine, Fawcett, Szűcs, and Dowker (2012) found similar results; however, Zettle and Raines used the Test Anxiety Inventory (Spielberger et al., 1977) and the Mathematics Anxiety Rating Scale (Suinn, 1972) while Devine et al. used the Abbreviated Mathematics Anxiety Scale (Hopko, Mahadevan, Bare, & Hunt, 2003) and the Test Anxiety Scale (Sarason, 1978). The different mathematics anxiety surveys mentioned attempts to measure mathematics anxiety but they measured different aspects of mathematics anxiety; thus, the fact that different mathematics anxiety surveys had similar results with test anxiety surveys indicated mathematics anxiety might not be a subconstruct of test anxiety.

Green (1990) examined relationships among test anxiety, mathematics anxiety, teacher feedback, and achievement in undergraduate students attending a remedial mathematics course. To measure test anxiety and mathematics anxiety, she utilized the Test Anxiety Scale (Sarason, 1978) and a revised version of the Mathematics Anxiety

Scale (Fennema & Sherman, 1976) for college students. Green found the multiple regression equation containing only test anxiety as the independent variable and mathematics achievement as the dependent variable was significant. Also, the multiple regression equation containing independent variables of test anxiety, mathematics anxiety, teacher feedback, and mathematics ability and the dependent variable of mathematics achievement was significant; however, test anxiety was the only significant predictor in the model. This finding indicated test anxiety and mathematics anxiety are separate constructs; otherwise, the model with mathematics anxiety as the only independent variable and mathematics achievement as the dependent variable should have been significant.

Dew and Galassi (1983) conducted one of the first studies that quantitatively examined whether mathematics anxiety and test anxiety were separate constructs; however, they were not the only researchers to question this. Brush (1978), D'Ailly and Bergering (1992), Hunsley (1987), Kagan (1987), Wigfield and Meece (1988), and Wood (1988) also pondered this distinction in their work. Dew, Galassi, and Galassi(1984) investigated different aspects of mathematics anxiety using the Mathematics Anxiety Scale (Fennema & Sherman, 1976), Anxiety Towards Mathematics Scale (Sandman, 1974), and Mathematics Anxiety Rating Scale (Suinn, 1972) to measure mathematics anxiety while measuring test anxiety using the Test Anxiety Inventory (Spielberger et al., 1977). They found all four anxiety surveys were positively and significantly correlated; however, even though all of the mathematics anxiety surveys were strongly correlated with each other, the Test Anxiety Inventory was only moderately correlated with each mathematics anxiety survey. This difference led researchers to conclude mathematics anxiety and test anxiety are not the same construct but are related. The researchers continued to investigate this relationship with another population in Dew et al. who had similar results.

One of the aspects of mathematics anxiety Hembree (1990) examined using correlational analysis was whether test anxiety subsumed mathematics anxiety. He found test anxiety and mathematics anxiety had several of the same properties: both anxieties related to general anxiety; differences in anxiety level with respect to ability, gender and ethnicity were similar for both anxieties; both affected performance in a similar way; both responded to the same treatment methods; and improved performance was related to lower mathematics and test anxiety. Even with these same properties and a moderate correlation between test and mathematics anxiety, Humbree found only 37% of one construct's variance was predictable from the other construct's variance. This meant 63% of the variance must be due to other sources absent in the other construct. From this, Humbree concluded mathematics anxiety and test anxiety were most likely separate constructs; in particular, mathematics anxiety seemed not restricted to testing but also included a general fear of contact with mathematics.

In most recent years, Kazelskis et al. (2000) stated a similar conjecture on test and mathematics anxiety. They conducted correlational and confirmatory factor analyses to examine the relationship between measures of mathematics and test anxiety. The Mathematics Anxiety Scale (Fennema & Sherman, 1976), the Mathematics Anxiety Rating Scale (Richardson & Suinn, 1972), the Mathematics Anxiety Questionnaire (Wigfield & Meece, 1988), and the Anxiety Towards Mathematics Scale (Sandman, 1979) were utilized to measure mathematics anxiety while test anxiety was measured with the Test Anxiety Inventory (Spielberger et al., 1977), the Achievement Anxiety Test (Alpert & Haber, 1960), and the Suinn Test Anxiety Behavior Scale (Suinn, 1969). The correlations among the mathematics anxiety surveys were in the range of moderate to high. The correlations among the mathematics anxiety surveys and the test anxiety surveys were nearly as high. The researchers reasoned mathematics anxiety surveys might be tapping into different parts of mathematics anxiety, which would explain the low correlations among them. Also, all of the mathematics anxiety surveys contained items about mathematics test anxiety, which meant those surveys were tapping into mathematics test anxiety. Based on their results, the researchers concluded mathematics anxiety and test anxiety might be separate constructs; however, more research needs to be done especially in terms of the conceptual and measurement differentiation between the two anxieties.

From the research, mathematics anxiety and test anxiety ranged from moderately to highly correlated but was dependent on the instruments used. Conceptually, mathematics anxiety and test anxiety are separate constructs because mathematics anxiety includes all anxiety related to mathematics while test anxiety focuses on the testing environment, which is only a part of the mathematics classroom. Although little recent research has examined the relationship between mathematics and test anxiety, what does exist seems to indicate mathematics anxiety and test anxiety are more likely separate constructs rather than mathematics anxiety being a subconstruct of test anxiety. In the light of these findings, mathematics anxiety was assumed to be separate but related to test anxiety in this dissertation study.

Mathematics anxiety and mathematics achievement. Due to the historical development of mathematics anxiety from test anxiety, the relationship between mathematics anxiety and mathematics achievement stems from the relationship between test anxiety and achievement. According to Ashcraft and Moore (2009), two papers (Dreger & Aiken, 1957; Gough, 1954) were instrumental in the development of exploring mathematics anxiety. Gough (1954) reported about a teacher who mentioned her students' emotional difficulties with mathematics while Dreger and Aiken (1957) created the first mathematics anxiety survey by adding three math-related items to the Taylor Manifest Anxiety Scale (Taylor, 1951). Due to the relationship between test anxiety and achievement, one of Dreger and Aiken's (1957) predictions was there would be an inverse relationship between mathematics anxiety and mathematics achievement. This prediction has been confirmed repeatedly throughout the years but not until the 1970s when more rigorous research on mathematics anxiety began with the appearance of instruments designed specifically to measure mathematics anxiety such as Richardson and Suinn's (1972) Mathematics Anxiety Rating Scale and Fennema and Sherman's (1976) Mathematics Anxiety Scale. The research relating mathematics anxiety and achievement provided insight into answering the sixth and seventh research questions.

Hembree’s (1990) seminal meta-analysis confirmed Dreger and Aiken's (1957) prediction by summarizing mathematics anxiety findings of 151 studies including 49 journal articles and 75 doctoral dissertations. He found mathematics anxiety and mathematics achievement were inversely correlated across all grade levels; in other words, higher mathematics anxiety correlated with lower mathematics achievement. In particular, this relationship was stronger for males than females in 5th through 12th grades; however, the gender difference disappeared for college students. Also, while examining the 13 studies of college mathematics that compared high anxiety and low anxiety students' performance, Hembree found lower anxiety students consistently performed better. Due to the examination of evidence from studies Hembree reviewed, the relationship between mathematics anxiety and mathematics achievement differed depending on grade level. As this dissertation work focused on pre-service elementary teachers, I provide a summary of the literature on the connection between mathematics anxiety and mathematics achievement specifically at the college level.

Several studies conducted before Hembree's (1990) meta-analysis had similar findings for the aforementioned relationship between mathematics anxiety and mathematics achievement (Aiken, 1970; Betz, 1978; Clute, 1984; Hendel, 1977; Richardson & Suinn, 1972). However, Llabre and Suarez (1985) found that mathematics anxiety does not significantly improve the prediction of college algebra grades once mathematics aptitude, which was measured using the mathematics section of the Scholastic Aptitude Test, has been accounted for. Mathematics anxiety studies conducted after Hembree’s meta-analysis also supported this inverse relationship. For example, Green (1990) found a significant amount of variance in mathematics achievement was accounted for by mathematics ability, test anxiety, teacher comments, and mathematics anxiety. In this model, as all the other independent variables stayed constant and mathematics anxiety increased, mathematics achievement decreased. Norwood (1994), Sharp, Coltharp, Hurford, and Cole (2000), Legg and Locker (2009), and Andrews and Brown (2015) also found significant negative and moderate correlations between mathematics anxiety and mathematics achievement.

Hembree (1990) not only examined the relationship between mathematics anxiety and mathematics achievement but also the methods used to treat mathematics anxiety in order to improve mathematics achievement. Methods examined were classroom interventions and out-of-class behavioral, cognitive, and cognitive-behavior psychological treatments. Classroom interventions, which were curricular changes as a means to reduce mathematics anxiety, and whole-class psychological treatments were found ineffective in reducing mathematics anxiety. Some behavioral treatments (systematic desensitization, anxiety management training and conditioned inhibition) helped reduce mathematics anxiety. Systematic desensitization is a treatment for phobias in which the patient is exposed to progressively more anxiety-provoking stimuli and taught relaxation techniques. Anxiety management training is a method where people are taught techniques to deal with anxiety. Conditioned inhibition is a classical conditioning technique in which one conditional stimulus is always paired with an unconditional stimulus (mathematics anxiety) to reduce the strength of the unconditional stimulus. Other treatments that helped reduce mathematics anxiety were cognitive modification to restructure faulty beliefs and build self-confidence in mathematics; cognitive restructuring was combined with systematic desensitization or relaxation training. Cognitive treatment of group discussion and relaxation training by itself were not effective. In particular, effective behavioral and cognitive-behavioral treatments significantly increased mathematics test scores while cognitive modification that emphasized confidence building produced a moderate increase in test performance.

A few other researchers examined methods to decrease mathematics anxiety and increase mathematics achievement. Clute (1984) used two different instructional practices in two college mathematics survey courses that taught logical problem-solving and critical thinking of various mathematics topics. The direct instruction expository method consisted of lectures designed to assist students in mastering an organized body of knowledge while the direct instruction discovery method was designed to guide students in discovering mathematical principles through questioning sequences. The expository method seemed to be similar to a traditional lecture method except a few practice problems were added to the end of the lecture for students to practice. The teacher reviewed the previous day's material to lead to the current day's material, then covered new material for the day, and finally summarized the material before allowing students time to work on some practice problems. The discovery method was described as when an instructor gave students a major mathematics problem and had them discover the solution by having students share their solutions and having the teacher respond to the students by letting them know whether the solution was correct, partially correct, or wrong. If the solution was partially correct or wrong, the teacher then asked the class related questions to get them closer to the solution. Clute found high anxiety students benefited more from the lectures while low anxiety students benefited more from discovery learning. This finding contrasted with findings by Kogan and Laursen (2014) in which inquiry-based learning (IBL) teaching practices benefited low achieving students more than high achieving students; however, they focused more on achievement and did not examine the effect of IBL on mathematics anxiety. Norwood (1994) also examined the use of two different instructional practices in a developmental arithmetic course at a community college. One approach emphasized memorization of mathematics rules and formulas while the other approach emphasized conceptual understanding and presented mathematics as a group of related concepts. The findings were similar to Clute with high anxiety students preferring the memorization of rules and formulas due to the course being highly structured and algorithmic. Sharp et al. (2000) examined the effectiveness of relaxation training on mathematics anxiety and achievement in an undergraduate mathematics classroom. One class had relaxation training during the second to seventh day of class and then used that technique to relax for the first five to seven minutes of each class after that while the other class was the control class. The relaxation training involved students closing their eyes and listening while a script was read, which was designed to make a person feel relaxed. The class that received relaxation training had significantly lower mathematics anxiety and higher mathematics achievement when compared to the control class. This finding contradicted Hembree (1990) who found relaxation training alone was not effective in reducing mathematics anxiety and increasing mathematics achievement; however, this might have been due to different methods used for relaxation training.

Students' mathematics anxiety affects their mathematics achievement in the classroom; in particular, the higher a student's mathematics anxiety, the lower his/her mathematics achievement. Additionally, methods designed to decrease mathematics anxiety have led to an increase in mathematics achievement. Overall, a significant relationship was found between mathematics anxiety and mathematics achievement, hindering students' performance and possibly their confidence to do mathematics. Research related to mathematics anxiety and achievement are examined further in Chapters II and III.

Mathematics anxiety and mathematics self-efficacy. With the appearance of mathematics anxiety as its own separate construct from test anxiety and it having a relationship to achievement, researchers have attempted to better understand the complexity of mathematics anxiety. Researchers have attempted and are continuing to attempt to explore this relationship by finding other variables that have a significant relationship with mathematics anxiety and/or a possible mediating effect on the relationship between mathematics achievement and mathematics anxiety. Since self-efficacy has been shown to influence a person's choice and persistence in mathematics-oriented careers (Ellis, Fosdick, & Rasmussen, 2016; Hackett, 1985; Lent, Brown, & Larkin, 1984) and mathematics performance affects a person's career choice, several researchers have examined the relationship between mathematics anxiety and self-efficacy.

One earlier study to examine this relationship in the United States was Cooper and Robinson (1991) who examined factors that could possibly influence mathematical and career self-efficacy and mathematics performance in undergraduates. One finding was mathematics anxiety and mathematics self-efficacy were significantly and negatively correlated at a moderate level. Hoffman (2010), Lent, Lopez, and Bieschke (1991), and Pajares and Miller (1994) had similar findings while Jameson and Fusco (2014) found that as participants' age increased, their anxiety also increased and their self-efficacy decreased among undergraduate students. However, Walsh (2008) found no significant relationship between mathematics anxiety and self-efficacy in basic and complex dosage calculations in associate degree nursing students. As for K-12 students, Jameson (2014) found mathematics anxiety and self-efficacy had a significant, but low moderate correlation for second graders. Pajares (1996) and Pajares and Kranzler (1995) also found mathematics anxiety and self-efficacy had a significant negative correlation at a high level with eighth graders and high schoolers, respectively. Pajares also found gifted students had a stronger relationship between the two constructs than did regular students. Overall, these studies indicated a negative correlation between mathematics anxiety and self-efficacy and this relationship became more extreme as people aged.

Besides conducting correlational analyses on the relationship between mathematics anxiety and self-efficacy, several researchers conducted path analyses to explore this relationship. Malpass, O'Neil, and Hocevar (1999), Meece, Wigfield, and Eccles (1990), Pajares (1996), and Pajares and Kranzler (1995) conducted path analyses involving mathematics anxiety and self-efficacy on 10th-12th graders, seventh-ninth graders, eighth graders, and ninth-12th graders, respectively. They all found self-efficacy significantly predicted mathematics anxiety with a negative relationship. In other words, as self-efficacy increased, mathematics anxiety decreased. Also, self-efficacy had a significant and positive direct effect on mathematics achievement. Only Pajares and Kranzler's path analysis model showed mathematics anxiety affected mathematics achievement in a small negative way while the other researchers did not find any significant effect of mathematics anxiety on mathematics achievement.

Other non-U.S. researchers examined the relationship between mathematics anxiety and self-efficacy. In Turkey, Akin and Kurbanoglu (2011) and Kesici and Erdogan (2009) examined this relationship with university students while Yurt and Sahin (2015) examined it with sixth to eighth graders. Akin and Kurbanoglu and Kesici and Erdogan found mathematics anxiety and self-efficacy were negatively correlated at a significant level and self-efficacy predicted mathematics anxiety in a negative way. Yurt and Sahin found students with high intrinsic goal orientation, task value, control beliefs for learning and self-efficacy perception, and low test anxiety had less mathematics anxiety. In England, McMullan, Jones, and Lea (2012) found a high negative correlation between mathematics anxiety and self-efficacy in British nursing students. Dennis, Daly, and Provost (2003) found a similar correlation for Australian undergraduates. Also, Luo, Wang, and Luo (2009) found a high negative correlation for seventh to 12th graders in China while Jain and Dowson (2009) found a high, moderate, negative correlation for Indian eighth grade students.

For the world, mathematics anxiety and self-efficacy are significantly correlated in a negative direction excluding the study conducted by Walsh (2008). This might be due to the participants in Walsh’s study being nursing majors getting their associates degree while the other college studies were with undergraduate students in bachelor’s degree programs. In the United States, students' mathematics self-efficacy affects their mathematics anxiety; in particular, the higher a student's mathematics self-efficacy, the lower his/her mathematics anxiety. Given the relationships among mathematics anxiety, mathematics achievement, and self-efficacy, mathematics anxiety might be a mediating variable between the other two constructs. Considering calibration accuracy is the accuracy of self-efficacy, mathematics anxiety could be a mediating variable in the relationship between calibration and mathematics achievement; hence, it was considered in this dissertation work. This research provided insight into the relationship between mathematics anxiety and calibration.

Mathematics anxiety and self-regulation. Self-regulated learning "refers to the self-directive processes and self-beliefs that enable learners to transform their mental abilities, such as verbal aptitude, into an academic performance skill, such as writing" (Zimmerman, 2008, p. 166). Due to self-efficacy being a self-belief that allows learners to transform their abilities into performance, self-efficacy could be a part of self-regulation. However, some researchers found self-regulation is a predictor of self-efficacy (e.g., Pajares, 1996; Zimmerman, Bandura, & Martinez-Pons, 1992) while others found self-efficacy is a predictor of self-regulation (e.g., Malpass et al., 1999). Because of this uncertain relationship between self-efficacy and self-regulation, several researchers have examined the relationship among self-regulation and other variables related to self-efficacy. In particular, some mathematics education researchers have examined the relationship between mathematics anxiety and self-regulation along with their connection to achievement.

As mentioned in the calibration and achievement section, Pajares (1996) examined the role of self-efficacy in mathematics problem solving of regular and gifted eighth graders. Some variables he examined in his path analysis were self-efficacy for self-regulation, mathematics self-efficacy, mathematics anxiety, and mathematics performance. He found mathematics anxiety and self-regulation had a significant negative correlation at a moderate level for both gifted and regular students. Shores and Shannon (2007) and Jain and Dowson (2009) found similar findings when examining fifth and sixth graders, and eighth graders, respectively, but the correlations were at a low level.

Pajares (1996) also found self-efficacy for self-regulation had a direct positive effect on mathematics self-efficacy and a negative direct effect on mathematics anxiety for regular students while self-efficacy for self-regulation only had a positive direct effect on mathematics self-efficacy for gifted students. Additionally, mathematics self-efficacy had a positive direct effect on mathematics performance, while mathematics anxiety had no effect on mathematics performance for both groups. Jain and Dowson (2009) had a similar finding using factor analyses and structural equation modeling—self-regulation had a positive direct effect on self-efficacy, which in turn had a positive direct effect on mathematics anxiety. Unfortunately, they did not include any measure of mathematics achievement in their data or models. Malpass et al. (1999) had a similar but slightly different finding when examining the relationship among self-regulation, self-efficacy, and mathematics anxiety. First, the researchers did not examine all of mathematics anxiety but examined a subconstruct of it instead, which they referred to as *worry*. Worry is the cognitive component of anxiety while the other subconstruct is emotionality, which represents the physiological/affective component. Second, they found the same relationship in their path analysis that Pajares found for his regular students in his path analysis with worry replacing mathematics anxiety except that self-efficacy had a positive direct effect on self-regulation. As a result, self-regulation had no effect on mathematics achievement. Shores and Shannon (2007) also found self-regulation was not a significant predictor of mathematics achievement.

Kesici and Erdogan (2009) went a step further and examined whether components of self-regulation had any significant relationship with mathematics anxiety in college students. The instrument they used to measure self-regulation was the Motivated

Strategies for Learning Questionnaire (Pintrich, Smith, Garcia, & McKeachie, 1991), which included a scale called the Learning Strategies Scale. This scale had subscales representing rehearsal, elaboration, organization, critical thinking, metacognitive self-regulation, time and study environment management, effort regulation, peer learning, and help seeking. They found only rehearsal and elaboration were significant predictors of college students' mathematics anxiety.

Kramarski, Weisse, and Kololshi-Minsker (2010) examined how self-regulated learning by itself and with metacognitive questioning affected third grade students' mathematics anxiety and problem-solving performance. In the classroom, self-regulated learning "refers to a cyclical and recursive process that utilizes feedback mechanisms for students to understand, control, and adjust their learning accordingly" (Kramarski et al., 2010, p. 180). To help students understand, control, and adjust their learning, the researchers included metacognitive questions for one class but not for the other. The metacognitive questions involved comprehension questions designed to prompt students to think about the task before solving it, connection questions designed to prompt students to compare actions they had done and explain why they had taken those actions, strategic questions designed to prompt students to think about what strategies to use to solve a problem and for what reasons, and reflection questions designed to prompt students to self-regulate their problem solving. Students in the self-regulated learning class with metacognitive questioning received those cards at the beginning of the study and were encouraged to use them when solving problems throughout the study. They found the self-regulated learning students with metacognitive questioning had better mathematics performance and greater reduction in mathematics anxiety.

Mathematics anxiety and self-regulation are significantly correlated in a negative direction. Some conflicting results were found on whether self-regulation affects mathematics anxiety directly as in the case of Malpass et al. (1999) or its effect on mathematics anxiety as mediated by self-efficacy as in the cases of Pajares (1996) and Jain and Dowson (2009). Students' mathematics self-regulation affected their mathematics anxiety; in particular, the higher students’ mathematics self-regulation, the lower their mathematics anxiety. Given the relationships among mathematics anxiety, self-efficacy, and mathematics achievement, self-efficacy and mathematics anxiety could be mediating variables between self-regulation and mathematics achievement. Because calibration informs students how well their perceived performance corresponds to their actual performance on a task, this potentially could lead to students self-regulating their mathematics learning in some manner that benefits them. This then could lead to a reduction in mathematics anxiety, which in turn could lead to an increase in mathematics achievement. In other words, mathematics anxiety could be a mediating variable in the relationship between calibration and mathematics achievement.

Mindset in Mathematics

In the last couple of decades, mindset has become an important topic within education. Mindset relates to how people view their intelligence. There are two extremes of mindset – fixed and growth. Fixed mindset people view their intelligence as something set in stone; in other words, they cannot change it no matter how hard they try. Growth mindset people view their intelligence as something that can change and grow. Dweck (2006) described the influence of mindset on people. Mindset changes the meaning of failure and effort. Fixed mindset people view themselves as failures once they fail at something and tend to avoid that situation again; if they must put in effort to do something, they do not possess the ability to do so and should not bother. Growth mindset people view failure as a temporary outcome they can rectify through effort as their effort will lead to the ability to challenge their previous failure. This means growth mindset leads people to embrace challenges and effort while fixed mindset causes people to fear challenge and devalue effort. As a result, fixed mindset makes people into non-learners because they do not want to expose their deficiencies and their ability should show immediately when working on something. Meanwhile, growth mindset people believe learning involves reflecting and learning from their mistakes; as such, they seize the chance to learn even if it shows their deficiencies. This creates resilience in the face of setback and greater success.

For example, Dweck (2006) mentioned that students with growth mindset view a poor test grade as something they need to improve by studying harder for the next exam, while those with a fixed mindset view it as something they need to avoid by studying less for the next exam as they do not possess the ability to do it and might consider cheating on the next exam. Dweck found fixed mindset students showed a decline in their grades while growth mindset students showed an increase in their grades after following junior high students for a couple of years. Also, she found growth mindset students tended to take charge of their learning and motivation to better understand the material and went beyond rereading the course materials for memorization that fixed mindset students did. This finding indicated fixed mindset also caused the utilization of inferior learning strategies, which might be partly due to the view that other people are judges instead of allies to fixed mindset people. Thus, I examined the mindset literature relating to mathematics achievement, anxiety, and calibration.

Mindset and mathematics achievement. The examination of the relationship between mindset and mathematics achievement came about due to the mindset work of Carol Dweck (2006). From her work, other researchers found interesting results related to mathematical learning. Boaler (2014) found there tends to be a high level of fixed mindset thinking among girls, which is one reason girls tend to avoid science, technology, mathematics, and engineering subjects (Perez-Felkner, McDonald, Schneider, & Grogan, 2012). Perez-Felkner et al. (2012) also found females who took advanced mathematics classes in secondary school and majored in science, technology, engineering and mathematics (STEM) tended to have more fixed mindset than those majoring in STEM who did not take advanced mathematics. Also, Leslie, Cimpian, Meyer, and Freeland (2015) found mathematics was the subject professors held the most fixed mindset beliefs about concerning who could learn the material. This is an issue as mathematical mindset held by teachers tends to influence students' mindset to become similar to that of their teachers (Boaler, 2016). Relating to the previous literature about mindset and achievement, Boaler (2016) found highest-achieving students on the Program for International Student Assessment 2012 had a growth mindset and outranked other students by an equivalent of more than a year of mathematics. Dweck and Boaler's (2016) work seemed to indicate mindset affects mathematical achievement. As such, I examined recent literature about this relationship to provide insights into the fifth and seventh research questions.

Aronson, Fried, and Good (2002) sought to reduce stereotype threat on African American college students through adjustment of their mindset. The researchers randomly placed African American and White students into a treatment or one of the two control groups. The treatment group wrote letters to middle schoolers about how intelligence was malleable and could grow with effort, one control group also wrote letters but without the message about intelligence being malleable, and the other control group did not write a letter. Following their academic progress for the first year, the African American students in the treatment group performed better in their classes than the two control groups, which included mathematics courses. The White students in the treatment had a similar response but not to as large of a degree as the African American students.

Good, Aronson, and Inzlicht (2003) pursued improving standardized test performance for underrepresented groups by using interventions to reduce stereotype threats. One such intervention was to have seventh graders mentored by college students who encouraged them to view their intelligence as malleable (i.e., growth mindset) and assisted the seventh graders in creating a webpage that showed their understanding of the message about their intelligence. Another intervention combined this message with the message that academic difficulties were due to the novelty of the educational environment. This intervention followed the same format as the previous one. Using both of these interventions, the researchers found females performed significantly better on standardized math tests than females in the control group. However, this was not evident in minority and low SES students.

Blackwell et al. (2007) also investigated the role of mindset in seventh graders' mathematics achievement through two studies. One study surveyed students' mindset and achievement starting in seventh grade until they finished ninth grade. The students' performance on the Citywide Achievement Test in sixth grade and their semesterly performance in class for grades seven through nine were used to measure performance while mindset was measured using a theory of intelligence survey. They found students with a growth mindset had mathematics performance increase throughout their years while fixed mindset students had a very small, but downward change in their performance. These analyses indicated the difference in mathematics achievement was mediated by several key variables related to mindset. Growth mindset students were significantly more oriented toward learning goals and showed a stronger belief in the power of effort than did fixed mindset students. They believed effort encouraged ability growth and was effective regardless of current level of ability. Those with fixed mindset believed effort was necessary for those without ability and was not likely to be effective for them. Lastly, students with growth mindset showed more mastery-oriented reactions to setback by being less likely to belittle their ability and more like to employ greater effort and new strategies than fixed mindset students.

The second study tested a teaching intervention that taught students their intelligence was malleable. The intervention occurred once a week for eight weeks in which students in control and treatment groups learned about the brain, study skills, and anti-stereotypical thinking. The experimental group was taught that intelligence was malleable and could grow while the control group learned about memory and discussed academic issues of interest to them. They used sixth-grade mathematics grades as prior achievement and seventh grade fall and spring semester final mathematics grades to measure students' achievement. The treatment and control groups had a decrease in mathematics performance from sixth to seventh grade before the intervention. The control group continued this downward trend after the intervention while the treatment group reversed this trend and had an increase in mathematics achievement.

Howard and Whitaker (2011) examined the perspectives and experiences of newly successful developmental mathematics students; in particular, the experiences, attitude, and strategies these students believed were effective and ineffective in assisting their mathematical learning and understanding. The researchers conducted a phenomenological study by interviewing students, observing them in their developmental mathematics classroom, having them write a reflexive journal, and collecting their scores for exams, quizzes, and homework. They found each student indicated a previous negative experience in mathematics that led to unsuccessful mathematics learning and a more fixed mindset view. Also, they reflected on positive mathematical experiences that led to their change from a fixed mindset to a growth mindset. The growth mindset caused a change in students' mathematical learning strategies. In particular, students were motivated to identify and utilize effective learning strategies such as the realization that to learn mathematics from their teacher, they needed to be in class. In turn, this led to students being more successful in the course in their understanding and performance.

Claro et al. (2016) investigated the influence of structural factors such as SES and psychological factors such as mindset on academic achievement on national exams over mathematics and reading in Chile given to 10th graders. Data for the study were from the Chilean government from the 2012 exams. Mindset was measured by the government using a shortened version of Dweck's (2006) mindset survey. Students who agreed or strongly agreed with statements that indicated intelligence could not be changed were categorized as fixed mindset while those who strongly disagreed or disagreed with those statements were categorized as growth mindset. Students who did not fit in either of those categories were categorized as mixed mindset. Using regression analysis, Claro et al. found mindset was a significant predictor for students' mathematics achievement with a 0.13 standard deviation increase in performance for students changing from fixed mindset to growth mindset. Additionally, the researchers found growth mindset students performed better mathematically than fixed mindset at every level of students' SES and a growth mindset might mitigate the negative effects of low SES on achievement.

McCutchen et al. (2016) investigated the influence of mindset on standardized tests over time. The sample consisted of third to sixth graders. Over a two-year period, the mindset survey (Dweck, 1999) was given to students each semester for both reading and mathematics while reading and mathematics achievement was measured each semester using the Iowa Test of Basic Skills Form C. Using hierarchical linear modeling, they found change in mathematics achievement over the two years was dependent on the initial mindset of the students. Those with a more growth mindset at the beginning of the study had a slower decline on the standardized mathematics tests than those with a more fixed mindset. This was an interesting result as previous studies and Dweck's (2006) work had indicated mathematics growth in performance should occur for students with a growth mindset. However, this study was observational, which could indicate students decrease in mathematics performance in both the fixed and growth mindsets was related to students' learning environment. In particular, students could have been learning in an environment where fixed mindset ideology was rampant; as a result, their growth mindset degraded and became more fixed.

Students' mindset influences their mathematics achievement in the classroom; in particular, the more growth mindset a student possesses, the greater his/her mathematical performance. Additionally, the development of a growth mindset could assist female and low SES students in their mathematical performance. The power of growth mindset also affects long-term mathematical performance as growth mindset students are more apt to have better mathematical performance over time than fixed mindset students. Lastly, the development of growth mindset can occur through properly utilized reflection pieces.

Mindset and mathematics anxiety. There was no indication the relationship between mindset and mathematics anxiety has been examined in the literature. However, indications of the relationship are reflected in Dweck's (2006) research regarding the influence of mindset on resilience. As Dweck mentioned, she found mindset changed the meaning of failure and effort. Students with a fixed mindset avoid situations in which they have failed before while also not putting in effort to rectify the situation. In contrast, students with a growth mindset challenge their failures to improve their learning by putting in effort to shore up their misconceptions and missing knowledge. These differing points of view can lead to different meanings regarding mathematics anxiety. Fixed mindset students seem more likely to use their mathematics anxiety as an indicator of a mathematical topic to avoid because the anxiety indicated they are not comfortable with the topic and might fail to understand the topic. Meanwhile, growth mindset students seem more likely to use their mathematics anxiety as an indicator of where they need to focus their effort to better understand the material because the challenge that comes from not being comfortable with a topic is more likely to drive them to learn the material. Fixed mindset students then are more likely to become mathematically anxious while growth mindset students are more likely to become less mathematically anxious. This was further supported by Dweck (2006) who mentioned growth mindset created resilience in the face of setback; by Yeager and Dweck (2012) who found this situation also occurs when students learn mathematics; and by Johnston-Wilder et al. (2015) who indicated mathematical resilience leads to a decrease in mathematics anxiety. These research studies provided insight into the fourth research question.

Mindset and calibration in the mathematics classroom. Similar to the relationship between mindset and mathematics anxiety, no literature was found examining the relationship between mindset and calibration in mathematics; however, some literature indicated a possible relationship between the two constructs. Although I was unable to locate them, Dweck (2006) mentioned some studies she participated in where she and her colleagues "found that people greatly misestimate their performance and their ability. *But it was those with the fixed mindset who accounted for almost all the inaccuracy* [emphasis in original]. The people with growth mindset were amazingly accurate" (p. 11). According to Nelson and Narens's (1990, 1994) metacognitive model, students' mindset could affect students' view of their dynamic model as fixed mindset students were more apt to ignore indications of inadequacies, which could lead to a skewed dynamic model within the meta-level. Freund and Kasten (2011) also theorized growth mindset leads students to reflect on their performance more deeply and critically to better evaluate their errors to improve, which might affect the processes involved when calibrating. This was further supported by O'Keefe (2013) who indicated growth mindset students engage in self-assessment and self-evaluation methods that lead to actions that improve their understanding while fixed mindset students utilize self-assessment and self-evaluation methods that protect and maintain their self-image as capable individuals. As a result of such actions, we can expect fixed mindset students would be more overconfident (i.e., have larger positive calibration bias) than growth mindset students, which was supported by Ehrlinger, Mitchum, and Dweck (2016) regarding English comprehension.

One study was found that examined the relationship between calibration and mindset in accounting. Ravenscroft, Waymire, and West (2012) investigated the relationship among exam performance, global calibration bias, and mindset with accounting students. They found students with a more growth mindset possessed better global calibration bias than the more fixed mindset students. This supported theoretical arguments previously mentioned. This study along with the others in this section provided insight when addressing the first research question.

Pre-Service Elementary Teachers

The pre-service elementary teacher population is an important subpopulation of undergraduate students to examine as they are the first teachers children interact with in a formal educational setting. The way they interact with students and subject matters affects how their future students interact with those subjects and formal education as a whole. Understanding the ways in which we could improve mathematics education for the pre-service elementary teacher population would not only benefit this population but also help their future students in their mathematical endeavors. Some researchers have examined pre-service elementary teachers' mathematics anxiety, mindset, mathematics self-regulation, and mathematics self-efficacy. I examined the literature of each of these topics in relation to this dissertation.

Pre-service elementary teachers' mathematics anxiety. Mathematics anxiety research is important due to the inverse relationship between mathematics anxiety and constructs such as mathematics achievement, self-efficacy and self-regulation but it is even more important for pre-service elementary teachers. First, mathematics anxiety in pre-service elementary teachers seems to be more commonplace and higher than for students in other majors (Baloglu & Kocak, 2006; Bessant, 1995; Hembree, 1990; Kelly & Tomhave, 1985). Second, these students' mathematics anxiety can have negative consequences for their future students. One consequence of this particular issue could be instructors with mathematics anxiety spend less time teaching mathematics in their classes. This means their future students might not be spending enough time learning mathematics, which could hinder their students' future mathematical learning. Also, teachers' mathematics anxiety transfers to their students, which leads to lower mathematics achievement (Beilock et al., 2010; Gunderson et al., 2012; Jackson & Leffingwell, 1999). In this section, I describe the effect of mathematics courses on pre-service elementary teachers' mathematics anxiety and factors that influenced their mathematics anxiety from existing studies, which provided insight when addressing the sixth and seventh research questions.

Alsup (2005) examined the effects of traditional and constructivist instruction on 61 pre-service elementary teachers' mathematics anxiety in three sections of mathematics content courses – Mathematics Concept I and Mathematics Concept II – which were typically taken during the pre-service elementary teachers' junior year with a pre-requisite of college algebra. One Mathematics Concept I course was taught traditionally while a Mathematics Concept I course and a Mathematics Concept II course were taught in a constructivist manner. The traditional course was taught utilizing a lecture-recitation format of instruction while the constructivist instruction emphasized "active learning and student involvement and modeled after pedagogy employed by progressive, constructivist educators in elementary classrooms" (Alsup, 2005, p. 6). Mathematics anxiety was examined as whole and within its three subconstructs (mathematics test anxiety, numerical anxiety, and mathematics course anxiety) using pre- and post-surveys. The researcher found no significant differences in mathematics anxiety between the traditional and constructivist courses but he did find mathematics anxiety as a whole significantly decreased throughout the semester for both Mathematics Concept I courses. Also, mathematics test anxiety decreased for the traditional course while mathematics course anxiety had a slight non-significant increase for the Mathematics Concept II course. The researcher theorized the decrease in mathematics anxiety for the Mathematics Concept I courses was due to the instructor's personality and teaching style while the increase in mathematics course anxiety in the Mathematics Concept II course was due to students having less familiarity with the materials and some of the students felt they were used as guinea pigs. These findings indicated that even though the courses in my study were taught from a constructivist/social constructivist viewpoint, I should not expect the pre-service elementary teachers' mathematics anxiety to decrease due to the viewpoint adapted in the design of these courses. Instead, the participants' mathematics anxiety would depend more on their teacher's personality and teaching style.

Tooke and Lindstrom (1998) also examined different teaching methods and their effect on pre-service elementary teachers' mathematics anxiety along with a different type of course. One section of mathematics for elementary teachers was taught in a traditional manner, another section was taught according to the recommendations of the National Council of Teachers of Mathematics (NCTM, 1989), and two sections of a methods course covered the same mathematics content as the other two courses. The traditional course consisted of lecture, homework, and examinations while the NCTM recommendation course consisted of open-ended questions being asked, group work, and the use of manipulatives. The two methods courses covered the same mathematical content as the mathematics courses but also discussed appropriate pedagogy for teaching the content to elementary students. When comparing the pre- and post-surveys of mathematics anxiety, the researchers found mathematics anxiety reduced for all the courses but was only significant for the methods courses. The researchers suggested this finding was due to the way the mathematics content was presented to the methods courses in comparison to the mathematics courses. The mathematics courses presented the mathematics material to the students as “this is what you must learn” while the methods courses presented the material as “this is how children learn this.” This seemed to indicate that presenting mathematics in a manner that prepares pre-service elementary teachers for their future career could reduce mathematics anxiety, which is the way instructors in my study usually presented the mathematics material.

Other researchers have examined possible factors that affect mathematics anxiety in pre-service elementary teachers. Unglaub (1997) interviewed six high mathematics anxiety and six low mathematics anxiety pre-service elementary teachers to determine why their mathematics anxiety existed and how they coped with it. The students were interviewed three times throughout a semester. The interviews examined the history of the students concerning mathematics and mathematics anxiety and the feelings of the students about teaching mathematics. They found the factors that influenced mathematics anxiety positively or negatively were the students' previous teachers, mathematics teaching methods used by previous teachers, and family mathematics history. The low mathematics anxiety students mentioned “good” mathematics teachers were a major cause of mathematics success and lack of mathematics anxiety. “Good” mathematics teachers made the class enjoyable for the students in some way. The high mathematics anxiety students mentioned mathematics teachers intimidated them, felt the grading was unfair, and/or the teaching methods of the mathematics instructor did not work for them. Also, the high mathematics anxiety students avoided mathematics by taking only the required mathematics courses and avoiding part-time jobs that were mathematics oriented.

Harper and Daane (1998) also examined factors that created mathematics anxiety in pre-service elementary teachers. They analyzed the mathematics anxiety levels of pre-service elementary teachers before and after a mathematics methods course and interviewed students with the greatest mathematics anxiety differences in the pre- and post-surveys for mathematics anxiety. They interviewed 11 students; six of them had a decrease in mathematics anxiety over the semester while the other five students had an increase. In the interviews, participants were asked what past experiences led to their mathematics anxiety. Also, the researchers developed a factors-influencing mathematics anxiety survey from the literature for all pre-service elementary teachers from the methods course to complete. This survey indicated the main factors that contributed to pre-service elementary teachers' mathematics anxiety were working with world problems, an emphasis on the right answers and the right methods of solving the problem, fear of making mistakes, frustration at the amount of time it took to do word problems, an emphasis on timed tests, feeling dumb when unable to solve a mathematics problem, and having no confidence in their mathematics ability. The interviews indicated specific mathematics content, teacher instruction and attitude, specific episodes in mathematics classes, and aspects not directly related to the mathematics classrooms were past influences causing mathematics anxiety for the interviewees. Mathematics content ranged in topics from elementary school to high school. Students' mathematics anxiety was due to the way their teachers negatively interacted with them and how their teachers taught the course in a poor manner. Specific episodes in mathematics classes related to a teacher publicly embarrassing them, making them feeling stupid for asking a particular question, and the pressure from tests. Aspects not directly related to the mathematics classroom included slowness in learning, dyslexia, not being able to do certain mathematics, and parental pressure.

Trujillo and Hadfield (1999) had some similar findings when examining the causes of mathematics anxiety in pre-service elementary teachers. They measured 50 pre-service elementary teachers' mathematics anxiety and selected the five most mathematics anxious students who happened to be all females. Each student was interviewed about her past experiences with mathematics in elementary school, high school, and college along with her family environment and her opinion as to the causes of her mathematics anxiety. The researchers found negative school experiences, lack of family support, and general test anxiety were major causes of mathematics anxiety. The participants' negative school experiences related to “bad” teachers in the sense the teachers were intimidating and/or did not explain the mathematics content well. Lack of family support connected to the fact that one or both parents of the interviewees were uncomfortable with mathematics and were unable and/or unwilling to help them on mathematics homework. All the participants indicated test anxiety appeared when taking mathematics tests, which caused them to not do as well as they could have.

Other non-U.S. researchers have examined possible causes for mathematics anxiety in pre-service elementary teachers. Brady and Bowd (2005) found similar results to Harper and Daane (1998), Trujillo and Hadfield (1999), and Unglaub (1997) in that Canadian pre-service elementary teachers' mathematics anxiety was caused by previous teachers' attitudes and teaching methods. Bekdemir (2010) examined whether the worst experience and most troublesome mathematics classroom experience affected Turkish pre-service elementary teachers' mathematics anxiety. He found those who had either a worst experience and/or most troublesome mathematics classroom experience had significantly higher mathematics anxiety than those who did not have either of them. Uusimaki and Nason (2004) examined the causes of mathematics anxiety in Australian pre-service primary teachers. They found primary school experience in learning mathematics was the main cause of mathematics anxiety in their participants.

As prior research indicated, pre-service elementary teachers are one of the most mathematics-anxious populations at the college level (Baloglu & Kocak, 2006; Bessant, 1995; Hembree, 1990; Kelly & Tomhave, 1985). Their mathematics anxiety built over the years mainly from their experiences with intimidating teachers, and/or teachers' negative attitudes exuded towards them, but also from parental pressure and other pressures from outside the classroom. Luckily, some evidence indicates teaching mathematics content courses for pre-service elementary teachers from the viewpoint of their future students would help reduce their mathematics anxiety. These experiences and courses that affected pre-service elementary teachers' mathematics anxiety could also affect their calibration because less anxiety can lead to an increase in confidence; the difference in confidence and test scores is one way to measure calibration. Unfortunately, evidence is lacking for the connection between pre-service elementary teachers' mathematics anxiety and calibration as researchers have not examined self-regulation and self-efficacy with this population.

Pre-service elementary teachers' mindset. Mindset of pre-service elementary teachers is an important area of research as research has shown teachers' mindset and actions in the classroom can affect their students' mindset. Teachers praising students for their intelligence instead of praising their effort or strategy usage promotes a fixed mindset for students (Cimpian, Arce, Markman, & Dweck, 2007; Dweck, 2007; Kamins & Dweck, 1999; Mueller & Dweck, 1998). Cook, Komissarov, Murray, and Murray (2017) indicated formative instructor feedback in writing led to students developing a more growth mindset. Dweck (2008) discussed a couple of studies conducted in the mathematics classroom. Teachers with a growth mindset in mathematics were found to give more encouragement, support, and more concrete strategies students could use for improvement while fixed mindset teachers were more likely to comfort students by explaining some people are made for mathematics. Fixed mindset teachers tended to give male students more concrete suggestions for improvement than females. Also, the presentation of important mathematicians as people who were born as mathematics geniuses promoted a fixed mindset while the presentation of such people as people who worked and devoted themselves to mathematics promoted a growth mindset.

Jones, Bryant, Snyder, and Malone (2012) examined the mindset of pre-service and in-service teachers in educational psychology courses at three public universities. The students were asked to complete Dweck's (1999) Theories of Intelligence – Self Form for Adults. They found pre-service and in-service teachers' mindset tended to be on the growth mindset side of the scale. When comparing the two teacher groups, the groups did not significantly differ but in-service teachers had a slightly more fixed mindset. These findings might indicate pre-service teachers' mindset did not change much by the time they started teaching or the way their courses were taught did not change their mindset in the intended direction. These findings and implications might not apply to the mathematical mindset of pre-service teachers as Gunderson et al. (2012) indicated the mathematical environment might cause people's mindset beliefs to differ from their general mindset beliefs. These studies provided insight into the fifth and seventh research questions.

Outline of Dissertation

As part of the three-manuscript dissertation, I have prepared three manuscripts for submission to refereed journals. The three manuscripts together will answer the following research questions:

Q1 What is the statistical relationship between calibration and mindset for pre-service elementary teachers?

Q1a Is there a statistically significant difference in calibration over time for pre-service elementary teachers who demonstrate a fixed and those who demonstrate a growth mindset throughout the semester accounting for instructor and semester?

Q2 What is the statistical relationship between calibration and mathematics anxiety for pre-service elementary teachers?

Q2a Is the change in mathematics anxiety of underconfident pre-service elementary teachers statistically significantly different from the change in mathematics anxiety of overconfident teachers accounting for instructor?

Q3 What is the statistical relationship between calibration and mathematics achievement for pre-service elementary teachers?

Q3a Does calibration statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q4 What is the statistical relationship between mindset and mathematics anxiety for pre-service elementary teachers?

Q4a Is there a statistically significant difference in mindset between low, moderate and high math anxious pre-service elementary teachers at the beginning and end of the semester accounting for instructor and semester?

Q5 What is the statistical relationship between mindset and mathematics achievement for pre-service elementary teachers?

Q5a Is there a statistically significant difference in the change in mindset for students of different achievement levels accounting for instructor and semester?

Q6 What is the statistical relationship between mathematics anxiety and mathematics achievement for pre-service elementary teachers?

Q6a Does the change in mathematics anxiety statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q7 Does calibration, mindset, and mathematics anxiety predict mathematics achievement for pre-service elementary teachers?

Q7a Does calibration and mathematics anxiety statistically significantly predict mathematics exam performance in pre-service elementary teachers accounting for instructors?

Q7b Does calibration and mathematics anxiety predict final exam performance accounting for instructor?

Q7c Does mindset, calibration and mathematics anxiety predict mathematics exam performance in pre-service elementary teachers accounting for semester and instructor?

For each manuscript, I described the purpose of the manuscript, the research question(s), and data analysis. Each chapter expands upon the purpose, research questions and data analysis along with appropriate literature, results and discussion sections.

The purpose of the first manuscript was to investigate the relationship among calibration, mathematics anxiety, and mathematics achievement in pre-service elementary teachers. This was accomplished by addressing the following question to a sample of pre-service elementary teachers taking the first mathematics content course of a required three-course sequence at a university in the Rocky Mountain region during the fall 2015 semester:

Q7a Does calibration and mathematics anxiety statistically significantly predict mathematics exam performance in pre-service elementary teachers accounting for instructors?

The research question was answered using correlational analysis and linear mixed modeling. The most significant finding was that there was an interaction effect between teachers and prediction calibration bias, which indicates that teachers may be able to assist students in becoming less bias in their calibration.

In the second manuscript, I addressed dissertation research questions 2a, 3a, 6a and 7b listed in the Purpose and Research Questions section by investigating mindset in pre-service elementary teachers' relationship with mathematics anxiety, calibration and mathematics achievement in the first and third mathematics content course. More precisely, I answered the following research questions:

Q2a Is the change in mathematics anxiety of underconfident pre-service elementary teachers statistically significantly different from the change in mathematics anxiety of overconfident teachers accounting for instructor?

Q3a Does calibration statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q6a Does the change in mathematics anxiety statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q7b Does calibration and mathematics anxiety predict final exam performance accounting for instructor?

Data collected during the Spring 2017 semester were analyzed using two-way and mixed analyses of variance (ANOVAs) and multiple linear regression to answer the research questions. One of the findings from this study was that there seems to be a relationship between calibration and mathematics anxiety; in particular, as students becomes more mathematically anxious, they become less calibrated.

For the third manuscript, I addressed dissertation research questions 1a, 4a, 5a and 7c listed in the Purpose and Research Questions section by exploring the relationship between mindset and the other constructs, mathematics anxiety, calibration and mathematics achievement. The participants were pre-service elementary teachers enrolled in the first and third mathematics content course during the 2017 fall and spring semesters. To do this, I addressed the following research questions:

Q1a Is there a statistically significant difference in calibration over time for pre-service elementary teachers who demonstrate a fixed and those who demonstrate a growth mindset throughout the semester accounting for instructor and semester?

Q4a Is there a statistically significant difference in mindset between low, moderate and high math anxious pre-service elementary teachers at the beginning and end of the semester accounting for instructor and semester?

Q5a Is there a statistically significant difference in the change in mindset for students of different achievement levels accounting for instructor and semester?

Q7c Does mindset, calibration and mathematics anxiety predict mathematics exam performance in pre-service elementary teachers accounting for semester and instructor?

Data were analyzed using three-way and mixed ANOVAs, and multiple linear regression to answer the research questions. The key result of this study was mindset relates to the other constructs – calibration, mathematics anxiety, and achievement – in ways that indicate a more growth mindset leads to less mathematics anxiety, better calibration, and increased mathematics performance for pre-service elementary teachers.

Significance of the Research

Recently, mathematics anxiety researchers (e.g., Herts & Beilock, 2017; Ramirez et al., 2018) have been expanding upon the relationship between mathematics anxiety and achievement to investigate how mathematics anxiety influences mathematics achievement. The examination of mathematics anxiety and achievement within this dissertation answered Chang and Beilock's (2016) and Herts and Beilock's (2017) calls by investigating the factors, calibration and mindset, which could provide insight into students' study habits and learning of mathematics. Additionally, Carroll (2008) and Hacker et al. (2008b) called for researchers to investigate metacognition and calibration, respectively, in a natural setting (i.e., classroom).

The investigation of the relationship between calibration, mindset, mathematics anxiety, and achievement occurred within the mathematics content courses for pre-service elementary teachers. This particular population plays a vital role in shaping the future generation and it is important to explore the ways in which their learning experiences can be improved in tertiary settings. As research indicates that pre-service elementary teachers are more mathematics anxious than other undergraduate populations (e.g., Baloglu & Kocak, 2006; Novak & Tassell, 2017). Mathematics anxiety in pre-service elementary teachers can be an issue as their mathematics anxiety can transfer to their future students, and consequently, inhibit these students' mathematical learning and performance (Beilock et al., 2010; Gunderson et al., 2012; Jackson & Leffingwell, 1999).

Additionally, understanding the relationship between calibration, mindset, mathematics anxiety, and achievement can lead to the development and reexamination of teaching techniques that reduces mathematics anxiety, promotes growth mindset, and increases students' calibration ability in order to increase mathematics performance and learning. This is vital to pre-service elementary teachers as utilizing those teaching techniques in their mathematics content courses can provide experience from which they can draw when they teach in the future to promote the same ideas for mindset, calibration and mathematics anxiety for their students. This might also help avoid the development of teachers' false growth mindset (Dweck, 2015).

One of the key results of this dissertation is that there is an indication that the four constructs are related to each other. In Chapters II, III, and IV, the relationship among mathematics achievement and the other constructs of calibration, mindset and mathematics anxiety followed what was found in the literature. Additionally, based on the theoretical framework and literature in Chapters II, III, and IV, the relationship between all four constructs seems to be that mindset may influence mathematics anxiety, calibration, and mathematics achievement while mathematics anxiety may influence calibration and mathematics achievement.

Another important result that relates to the previous result was that teachers might influence the relationship between the four constructs within the pre-service elementary teachers' mathematics content courses. In Chapter II, there is an interaction between teacher and calibration bias that influences pre-service elementary teachers' exam performance, while there is an interaction between mathematics anxiety and teacher that influences final exam performance in Chapters III and IV. Additionally, there is an interaction between mindset and teacher that influences final exam performance in Chapter IV. Given that different teachers have different styles of utilizing the teacher- and/or student-centered approach, of communicating with their students, and giving feedback to the students on presentations, assignments and assessments, this indicates that instructors of pre-service elementary teachers need to be careful in their instruction methods in order to promote growth mindset, lower mathematics anxiety, and better calibration.

CHAPTER II

CONNECTING PRE-SERVICE ELEMENTARY TEACHERS' CALIBRATION, MATHEMATICS ANXIETY AND ACHIEVEMENT: A LINEAR MIXED MODEL ANALYSIS

Introduction

Since its start in the mid-1900's, mathematics anxiety research studies have explored the relationship between mathematics anxiety and other constructs (Ashcraft & Moore, 2009). As one of the most commonly explored constructs, mathematics achievement has been shown to negatively correlate with mathematics anxiety. Chang and Beilock (2016) provided a review of the existing studies investigating the link between mathematics anxiety and achievement, and found that this link is mediated by several different factors such as retrieval strategy usage, which occurs when a person solves a problem by directly recalling pre-existing known information. Imbo and Vandierendonck (2007) found that high mathematically anxious students have a higher threshold to select retrieval-based strategies for problem solving, and the reduced usage of those strategies was associated with poor mathematics performance. Additionally, Legg and Locker (2009) found that certain metacognitive skills, such as planning, checking, monitoring and evaluating behaviors during a task, moderated the link between mathematics anxiety and performance. According to Nelson and Narens's (1990) metacognitive model, these findings indicate that mathematics anxiety can influence students' metacognition facilities. In particular, mathematics anxiety could inhibit the usage of metacognitive facilities involved in students' confidence judgments.

According to Chang and Beilock (2016), "[g]iven the high prevalence of math anxiety and its significant negative relations to math proficiency, understanding the factors that explain the relation between math anxiety and math performance may provide valuable insights for boosting math achievement" (p. 33). One metacognitive factor that may help explain the link between mathematics anxiety and performance is calibration, which is defined as the degree to which a person's perceived performance on a task matches to his or her actual performance on that task (Hacker et al., 2008b; Nietfeld et al., 2006). Many studies have found that calibration positively correlates with achievement (e.g., Chen, 2003; Chen & Zimmerman, 2007; Hacker et al., 2008b). The reason for this correlation lies with the fact that accurate calibration allows students to know exactly what they need to study to better prepare for an exam, while inaccurate calibration causes students to spend too much time studying material they already know or not enough time on material they do not know (Hacker et al., 2008b; Stone, 2000). The present study examined the relationship between mathematics anxiety, calibration and mathematics achievement of pre-service elementary teachers.

Literature Review

Theoretical Framework for Calibration

Researchers have emphasized the importance of metacognition to learning in general and to a specific domain such as mathematics (Kramarski & Mevarech, 2003; Schoenfeld, 1983; Veenman et al., 2006). There are existing research studies on metacognition and learning but with sparse amount of them in mathematics education at the undergraduate level. Also, as researchers (Hacker et al., 2008b; Nelson & Narens, 1994) have pointed out, metacognition research studies lack cumulative progress that is partly due to researchers attempting to control variations in participants' cognition in laboratory settings. Hacker et al. (2008b) argued that there is a need for researchers "to go outside the laboratory into more ecologically valid environmental situations" such as classrooms (p. 429).

To address this concern of studying metacognition outside the laboratory setting and contribute to the progress of metacognition research, Hacker et al. (2008b) expanded Nelson and Narens's (1994) ideas to study calibration, one of the constructs of metacognition, in the classroom setting. In particular, they noticed the need to study students' calibration in the classroom because calibration for studying and taking exams in a classroom setting is different than in a laboratory study due to the underlying motivations, goals, and constraints that students possess by taking a particular course and the effect that exams have on their course grade. Calibration is related to students' self-regulation when studying and taking tests. The self-regulation that students exhibit can be defined through several differing metacognitive models. The metacognitive and self-regulated learning model utilized for this study is Nelson and Narens's (1990,1994) model that was further expanded by Van Overschelde (2008).

Nelson and Narens (1990) split mental processes into two levels, an object-level (i.e., cognition) and meta-level (i.e., metacognition) where the meta-level contains a dynamic model of the object-level. The information that flows from the object-level to the meta-level and meta-level to object-level are referred to as monitoring and control, respectively. Monitoring provides information from the object-level to the meta-level that effects the dynamic model, while control regulates the actions that occur at the object-level. Additionally, monitoring allows students to judge how well they are doing based on the information at the object-level, while control allows students to use that judgment along with their meta-level knowledge, strategies, and goals to determine what actions to perform at the object-level.

Van Overschelde (2008) extended Nelson and Narens's (1990, 1994) model by adding components to the meta-level that he believed was implied in their work. One particular component of interest is the perceived constraints people can have when preparing for a test. The perceived constraints limit a person's actions during metacognitive control. The constraints include internal and external forces such as expectations about the characteristics of a future exam and time limits for studying, respectively. The perceived constraints that Van Overschelde discussed adds an additional layer to Nelson and Narens's model that can help explain why students may make different decisions when regulating their studying under similar circumstances. Also, the perceived constraints can influence students' calibration.

Hacker et al. (2008b) discussed the placement of calibration in Nelson and Narens's (1990, 1994) framework that shows the memory stages. Calibration judgments can occur after acquisition and retention, but may be made either before or after retrieval. Judgments that occur before retrieval are referred to as calibration prediction judgments, while those that occur after retrieval are referred to as calibration postdiction judgments. Hacker et al. (2008b) view prediction judgments as a prospective monitoring judgment; in other words, they believe that students monitor their knowledge before the retrieval of knowledge to make their prediction judgments (e.g., assessing how well they know the material while studying for an exam). On the other hand, Koriat, Ma'ayan and Nussinson (2006) suggest placing the prediction judgments during or after the self-direct search phase within the retrieval stage because monitoring and control are ongoing and mutually informing processes. In the present study, these two perspectives were implemented where first Koriat et al.'s approach to prediction judgments was followed. Hacker et al.'s (2008b) view, which states postdiction judgments are a retrospective judgment and are similar to Nelson and Narens's confidence judgments after recall, was used in this study.

Calibration is important in self-regulated learning because accurate perceptions of performance can provide a better chance of triggering appropriate control actions. In particular, calibration not only provides information to the students about what has been studied well enough or needs additional studying, but also affects the control actions that students use when studying such as continuing to use a strategy, focusing on certain parts of a topic, or reworking an approach in an attempt to fix some deficiencies of a previous approach. These control actions depend on the confidence judgments made before (i.e. prediction judgments) or after (i.e. postdiction judgments) students attempt to solve problems and/or test their knowledge. These judgments can be used to determine calibration accuracy and calibration bias. Calibration accuracy is the measure of how close the perceived performance is to the actual performance, while calibration bias indicates whether a person under- or overestimates their ability and by how much. Overconfidence, underconfidence, and inaccurate judgments of one's capabilities can harm one's learning and motivation in mathematics (Hacker et al., 2008b; Ramdass & Zimmerman, 2008). If students overestimate their ability, then control actions necessary for students to attain greater understanding of a topic could fail to trigger. If students underestimate their ability, then students could misallocate study time to further understand a topic when in fact they already understand enough of the material for an assessment or assignment.

Consequently, the theoretical relationship between calibration and learning can be described mathematically as the inverse variation between learning and calibration bias and direct variation between learning and calibration accuracy. The inverse variation between learning and calibration bias is due to students' under- or overconfidence leading them to focus too much or too little on a topic, respectively; thus, the students do not allot their time in the most efficient manner when studying which in turn leads to students possibly not understanding all the material they need to succeed. The direct variation between learning and calibration accuracy is because students who are better calibrated have a better idea of what they know well and not so well. This leads them to focus on the material they are struggling with, which in turn should allow the students to learn all the material well enough by the time of an assessment.

Relationship Between Calibration and Mathematics Achievement

Calibration has been examined and measured in multiple ways throughout the years (Alexander, 2013). The most common method of examining calibration is through calibration accuracy and calibration bias. With these two measurements, the connection between calibration and achievement has been extensively examined in many different areas: reading (e.g., Kostons & de Koning, 2017), computer games (e.g., Nietfeld, Minogue, Spires, & Lester, 2013), research methods (e.g., Bol & Hacker, 2001) and psychology (e.g., Nietfeld et al., 2005). These studies have generally found that the better calibrated students are, the higher their achievement.

In studies focusing on mathematics, calibration and achievement have been found to be significantly correlated at the moderate or strong level (Chen, 2003; Chen & Zimmerman, 2007; Garcia et al., 2016; Ozsoy, 2012). In particular, calibration prediction and postdiction accuracies positively correlated with performance, while calibration prediction and postdiction biases negatively correlated with performance. In other words, as students become more accurate with their calibration and less confident, their mathematics performance becomes better. The negative correlation indicates underconfident students tend to perform better than overconfident students, which has been referred to as underestimation bias (Pajares, 1996; Rutherford, 2017; Stone, 2000). This may be due to the difference in the studying process and amount of time studying that underconfident students go through compared to overconfident students in their self-regulated learning. Also, students tend to be overconfident in their mathematical ability when attempting to calibrate (Dinsmore & Parkinson, 2013; Pajares & Kranzler, 1995; Pajares & Miller, 1994).

Chen (2003) conducted a path analysis on calibration and other possibly related constructs. Calibration accuracy had both a positive direct and negative indirect effect on mathematics performance. The negative indirect effect was mediated through self-efficacy beliefs, which has a positive effect on performance. Chen (2003) showed that calibration accuracy had an overall positive effect on mathematics performance. Also, prior mathematics achievement had an indirect effect on mathematics performance in which calibration was a mediating variable. This path analysis shows that a student's calibration influences their exam performance, which was also shown by Stankov et al. (2012). Thus, the relationship between calibration and mathematics achievement may be more complicated than indicated originally by the correlational analyses. In particular, the relationship may be cyclic, in which calibration affects mathematics achievement on a test, which in turn, affects future calibration on another exam.

Other researchers have found evidence that supports the relationship between calibration and mathematics achievement through comparisons of exam types (e.g., Pajares & Miller, 1997), longitudinal studies (e.g., Rinne & Mazzocco, 2014; Sheldrake et al., 2014), self-regulated learning interventions (e.g. DiGiacomo & Chen, 2016; Ramdass & Zimmerman, 2008; Zimmerman et al., 2011), gifted versus non-gifted comparisons (e.g., Pajares, 1996), and feedback type comparisons (Labuhn et al., 2010). Labuhn et al. investigated types of graphed feedback (individual vs. social comparison vs. no feedback) on calibration and mathematics performance for fifth graders and at-risk fifth graders. Calibration postdiction was more accurate and less biased for those who received feedback compared to those who did not, while feedback increased calibration accuracy and slightly increased performance in overconfident students. Additionally, social comparison feedback led to higher calibration prediction accuracy and less bias compared to individual feedback for overconfident students. The influence of feedback on calibration from this study contradicts Schraw et al. (1993) and Nietfeld et al. (2005) in which feedback did not affect calibration. However, Nietfeld et al. (2006) found that weekly practice of calibration prediction accuracy with feedback from the instructor improved calibration. Also, Hacker et al. (2000) reported that feedback only benefited high achieving students when the feedback was provided over several tests. This may indicate that feedback is useful only for those students who attempt some type of self-reflection as self-reflection can help students improve their calibration and performance in mathematics (DiGiacomo & Chen, 2016; Ramdass & Zimmerman, 2008; Zimmerman et al., 2011).

Relationship Between Mathematics Anxiety and Achievement

The association between mathematics anxiety and achievement has been and currently is an important area of research as mathematics anxiety has been found to effect mathematics performance and, in turn, students' science, technology, engineering and mathematics career success (Foley et al., 2017). One seminal meta-analysis involving mathematics anxiety and achievement was conducted by Hembree (1990). He summarized mathematics anxiety findings of 151 studies, which included 49 journal articles and 75 doctoral dissertations. He found that mathematics anxiety and mathematics achievement were negatively correlated across all grade levels; in other words, higher mathematics anxiety correlated with lower mathematics achievement. Other research studies (e.g., Andrews & Brown, 2015; Norwood, 1994; Sharp et al., 2000) found similar results since Hembree's (1990) meta-analysis with medium to high correlations. The Organization for Economic Cooperation and Development (OECD, 2013) reported the results of the 2012 Program for International Student Assessment (PISA) stating that students who reported higher levels of mathematics anxiety exhibited lower levels of mathematics performance than those who reported lower mathematics anxiety in 63 of the 64 educational systems. Also, 14% of the variation in mathematics performance was explained by the variation in mathematics anxiety. This connection held when controlling gender and socioeconomic status for the highest performing students.

Some researchers (e.g., Lukowski et al., 2016; Nunez-Pena, Suarez-Pellicioni, & Bono, 2013) have investigated the predictive nature of mathematics anxiety on mathematics achievement. For example, in their seminal work, Ashcraft and Kirk (2001) demonstrated mathematics anxiety can have a disruptive effect on working memory and, in turn, affect mathematics performance by showing that high mathematics anxiety students did somewhat worse than low anxiety students on complex addition problems, and did noticeably worse on the same problems when asked to hold a group of letters in their mind for recall later. Beilock and Carr (2005) and Raghubar, Barnes and Hecht (2010) continued the investigation of working memory's role in the mathematics anxiety and achievement link and showed that mathematics anxiety can deplete resources in working memory. A consequence of the depleted resources in working memory is that students' mathematical learning is obstructed, which then hinders their mathematics achievement. Additionally, Beilock and Carr (2005) along with Ramirez, Gunderson, Levine and Beilock (2013) and Vukovic, Kieffer, Bailey and Harari (2013) found that students with the highest capacity for working memory had the strongest negative connection between mathematics anxiety and achievement.

Chang and Beilock (2016) discussed similar findings relating to the effect of working memory on the mathematics anxiety and achievement link. Additionally, they summarized research about other individual and environmental factors that influence and/or mediate the link. The individual factors were split into cognitive, affective/physiological, and motivational. Besides working memory, other cognitive factors that mediates the mathematics anxiety and achievement relation are the retrieval-based strategy usage, and what students pay attention to when solving problems. The affective/physiological factors include increased cardiovascular activity, salivary cortisol concentration and brain activity in regions associated with pain perception and negative emotional processing. The motivational factor comprises of enhancing the approach style and lessening the avoidance style through the use of intrinsic and external motivations. The environmental factors were divided into teachers, parents, and students. In particular, teachers' mathematics anxiety and classroom activities, parents' mathematics anxiety, support and expectations, and students' perception of their classroom environment can help explain how mathematics anxiety develops and how mathematics anxiety relates to mathematics performance. Another environmental factor that has been recently investigated is time. Hunt and Sandhu (2017) found that time pressure (i.e. under a time limit or the presence of a clock) interacts with mathematics anxiety and the interaction influences mathematics performance. Grays, Rhymer and Swartzmiller (2017) indicated that explicit time (i.e. displaying a stopwatch to individuals and explicitly telling them of the time limit) is a mediating factor between mathematics anxiety and achievement.

Some researchers have examined the factors that influence mathematics anxiety and achievement of pre-service elementary teachers. One reason the researchers focused only on this population is that mathematics anxiety in pre-service elementary teachers seems to be more common and more prevalent than in students in other majors (Baloglu & Kocak, 2006; Bessant, 1995; Hembree, 1990; Kelly & Tomhave, 1985). A second reason is that these students' mathematics anxiety can have negative consequences for their future students because teachers' mathematics anxiety transfers to their students, which leads to lower mathematics achievement (Beilock et al., 2010; Gunderson et al., 2012; Jackson & Leffingwell, 1999). The factors found to influence mathematics anxiety and, in turn, mathematics performance were students' negative experiences with mathematics teachers (Brady & Bowd, 2005; Harper & Daane, 1998; Unglaub, 1997), mathematics teaching methods used by previous teachers (Brady & Bowd, 2005; Harper & Daane, 1998; Unglaub, 1997), family mathematics history (Trujillo & Hadfield, 1999; Unglaub, 1997), negative experiences in mathematics classes (Bekdemir, 2010; Harper & Daane, 1998; Trujillo & Hadfield, 1999; Uusimaki & Nason, 2004). Harper and Daane (1998) found additional factors that influenced mathematics anxiety such as working with word problems, an emphasis on the right answers and the right methods of solving the problem, fear of making mistakes, frustration at the amount of time it took to do word problems, an emphasis on times tests, feeling dumb when unable to solve a mathematics problem, and having no confidence in their mathematics ability.

Research Purpose and Questions

The aim of this study is to investigate two aspects of calibration in mathematics education that have not been explored in depth. First, previous mathematics education studies on calibration focused mainly on elementary and secondary students. The only study found to investigate calibration at the collegiate level was a dissertation done by Champion (2010), which examined pre-service secondary teachers. Another important undergraduate population to examine is pre-service elementary teachers because they need to know what they currently understand or do not understand in order to improve their knowledge and understanding of mathematics before teaching K-6 students. Otherwise, they may not be prepared to teach children certain topics and not realize it until it is too late, which may affect the children's belief in the teacher and, in turn, their understanding of mathematics. Also, pedagogical content knowledge intertwines with subject matter knowledge for teachers when they teach a particular topic (Ball, Thames, & Phelps, 2008; Hill et al., 2005); thus, developing an understanding of how to improve one's learning would benefit this particular population.

Second, no one has examined the relationship between calibration and anxiety in mathematics even though both of these constructs individually affect achievement. Chen (2003) along with Malpass et al. (1999), Meece et al. (1990), Pajares (1996) and Pajares and Kranzler (1995) indicate that calibration could influence mathematics anxiety and, as a result, influence mathematics achievement. In particular, a student becoming better calibrated also becomes more mathematics anxious. Whether the overall relationship between calibration and mathematics anxiety has a positive or negative influence on mathematics achievement is unknown because calibration has a positive influence on mathematics achievement, while mathematics anxiety has a negative influence. Given these deficiencies in the literature and the suggestion from Chang and Beilock (2016), this study is designed to contribute to the existing studies by examining the relationship between calibration, anxiety and achievement among a sample of pre-service elementary teachers by addressing the following research question:

Q1 Does calibration and mathematics anxiety statistically significantly predict mathematics exam performance in pre-service elementary teachers accounting for instructors?

Method

Sample

Participants were 129 undergraduates (89 freshmen, 25 sophomores, 9 juniors, 4 seniors and 2 unknown) enrolled in the first mathematics content course for pre-service elementary teachers in a required three-course sequence in a 15-week semester during the fall of 2015. Institutional Review Board (IRB) approval and consent form for this study can be found in Appendix A and B, respectively. Ninety-nine (76.74%) students provided complete data for the study. The course was taught in the mathematics department at four-year doctoral granting institution in the Rocky Mountain region. This course centered on the real number system and arithmetic operations with a focus on the structure and subsets of real numbers using patterns, relationships, and properties. Students met twice a week for 75 minutes and mostly worked in groups. Most of the participants were female (91.47%) and white, which was typical for this course at this university. Even though the course is primarily for elementary education students, students majoring in special education who focus on K-3 or K-12 education were required to take this course along with early childhood education majors who focus on K-3 education. Table 2.1 summarizes the number of participants majoring in early childhood education, elementary education, and special education along with concentration areas of the elementary education participants. Some students were counted twice in the table as some of them had dual majors or dual concentration areas. Most participants (79.07%) were purely elementary education majors, while 16 (12.40%) majored in only special education and 11 (8.53%) majored in only early childhood education.

Table 2.1

Majors and Concentration Areas of the Participants

Major	Concentration Area	Participants (N=129)
Early Childhood Education		16
Elementary Education	Biology	4
	Civics (Political Science)	1
	Creative Drama	1
	Earth Science	2
	ESL	26
	History	11
	Language Arts	24
	Mathematics	5
	Multicultural Studies	1
	No Concentration Mentioned	9
	Spanish	4
	Sports Medicine/Exercise Science	1
	Undecided	6
	Visual Arts (Arts Integration Emphasis)	1
	Visual Arts (Studio Emphasis)	1
Special Education		23

Measures

Data collected through mathematics anxiety surveys, graded exams and self-efficacy surveys were used to explore the relationship between the three research constructs, mathematics anxiety, mathematics achievement, and calibration. The following sections describe each of the surveys, the scoring for each survey if relevant to the study, and the reliability of each survey.

Mathematics anxiety. A ten-item survey (Appendix C) was developed by Van Gundy, Morton, Liu and Kline (2006) by modifying one of Fennema and Sherman's (1976) nine Mathematics Attitudes Scales. Van Gundy et al.'s anxiety survey focused on statistics anxiety. The wording of this survey was altered to measure mathematics anxiety in this study. For example, an original survey item was "I usually don't worry about my ability to solve statistics problems," while the rewording was "I usually don't worry about my ability to solve math problems." As a result, the ten items measured anxiety related to mathematics, working on mathematics problems, and taking mathematics tests. The survey was a four-point Likert-scale survey with response choices: strongly disagree, somewhat disagree, somewhat agree and strongly agree. The survey score ranged from 10 to 40 with a higher score indicating higher math anxiety. For the present study, the reliability of the survey was determined using Cronbach's alpha and test-retest reliability coefficient. The Cronbach's alphas were .91 and .92 for the first and second time the survey was administered, respectively, while the test-retest reliability coefficient was .78. These values are acceptable by Gall, Gall & Borg's (2007) cut off of .70.

Mathematics achievement on exams. The exams administered in the classes were created by the coordinator in conjunction with each of the instructors (see Appendix D for an example exam). For each administration of an exam, the same topics were covered by all the instructors, but some of the numbers and/or scenarios of the exam problems were altered by the instructors with approval from the coordinator. The first exam contained 11 problems, while the final exam had 18 problems and was a cumulative exam. The exams focused on mathematical content that the students might teach in the future. Consequently, each test had one or two problems that not only examined mathematical content, but were teaching application problems. Such problems examined how the students would guide a theoretical student to understand a concept or fix a misunderstanding. Most of these problems were open-ended questions with a couple of matching problems. The internal consistencies for the exams were reasonable with Cronbach's alphas of .76 and .80 for the first and final exam, respectively (Gall et al., 2007).

Self-efficacy. Self-efficacy surveys were developed from the instructor-made exams (see Appendix E for example survey). These surveys allowed students to estimate how well they anticipated doing on the exams. The instructors provided the researcher with a copy of the exam that included how much each problem was worth. Then the researcher added a highlighted line under each problem that said, "I will receive ___ points on this problem" which the student completed. Any extra space was removed so that students would not attempt to do the problem on the survey, and a cover page with instructions was provided. The Cronbach's alphas were reasonable with values of .66 and .89 for the self-efficacy of the first and final exam, respectively (Gall et al., 2007).

Procedure

One or two class days before the first exam students were asked to participate in the study. Those who agreed to participate were given the mathematics anxiety survey and consent form to fill out. Also, the participants completed the mathematics anxiety survey one week before the final exam. Immediately before the first and final exam, students were given the self-efficacy survey and were allowed up to seven minutes to complete the form. As students handed in their survey, they were given the exam to allow the student to take the remaining time to complete the exam. Copies of the graded exams were obtained from the instructors before they handed them back to the students. Anytime data were collected in the classroom, the instructors waited outside in order to keep students' participation confidential.

Data Analysis

Calculating calibration prediction accuracy and bias. The self-efficacy surveys were one way of measuring calibration prediction judgments; thus, the self-efficacy item scores were used to calculate calibration prediction accuracy. Calibration accuracy was calculated similar to the methods described by Hacker et al. (2008b). One main difference in methods for calculating calibration accuracy lay in the fact that the self-efficacy scores were point values, instead of a confident judgment using a 10-point or 100-point scale, or continuous confidence line. The other change in methods was that the calibration accuracy scores were standardized by dividing the sum of the absolute difference between the judged performance and the actual performance for each item by the total number of points each exam was worth. In other words, the formula for the calibration accuracy scores was as follows:

$$Calibration\ Accuracy = \frac{\sum_{i=1}^{n} |self-efficacy\ score\ on\ question\ i - actual\ score\ on\ question\ i|}{total\ points\ for\ the\ test},$$

where *n* represents the total number of problems on the exam. Using this calculation, calibration accuracy ranged from zero to one such that zero represents a person with perfect calibration and one represents a person with a complete lack of calibration. Calibration bias was calculated by dropping the absolute value in the previous calculation. The bias ranges from negative one to positive one where negative one represents a student with complete underconfidence, positive one represents complete overconfidence, and zero represents no under- nor overconfidence in a person's ability on a test.

Linear mixed model analysis. Due to the nature of the data and research question, a linear mixed model analysis was chosen as this analysis allows researchers to determine the possible effect of fixed effect variables on a dependent variable accounting for repeated measures and random effects. West, Welch and Galecki (2007) described how to conduct a linear mixed model analysis using SAS so it was used to guide the analysis of the data. To examine the possible effects of calibration and mathematics anxiety on exam performance, and to check for intrinsic aliasing issues (i.e. over-parameterization) in the linear mixed model analysis, I conducted correlational analyses. Besides having calibration accuracy, calibration bias and math anxiety as fixed effects in the model, the variables, time and teacher, were included as fixed effects, while the random effect was the participant. The linear mixed model analysis was conducted using a step-up strategy along with the covariance structure of variance components and the restricted maximum likelihood (REML) estimation method. Variance components was chosen due to other covariance structures discussed by West et al. (2007) causing the

Hessian matrix to be non-positive definite in SAS. The REML estimation method was chosen because it produces unbiased estimates for covariance parameters.

Results

This section summarizes the results of the statistical analyses conducted to answer the research question. First, the descriptive statistics results that are related to the research question are discussed. Then the correlational analysis between the key variables in the linear mixed model are examined. Lastly, the linear mixed model analysis is discussed.

Descriptive Statistics

Table 2.2 includes the descriptive statistics of the calibration accuracy, mathematics anxiety and exam performance. As summarized in Table 2.2, the calibration accuracy of the participating pre-service elementary students seemed to slightly decrease for each teacher throughout the semester. Meanwhile, students moved from being overconfident to underconfident for Teacher A, while the other two teachers' students went from being underconfident to overconfident. Similar to calibration accuracy, the students' mathematics anxiety decreased for each teacher through the semester. This could indicate that students' change in mathematics anxiety led to the change in calibration accuracy as mathematics anxiety was measured one or two class days before calibration accuracy. On the other hand, mathematics anxiety may not affect calibration bias in a consistent manner. This relationship will be examined further in the correlational analysis in a later section of the paper. Meanwhile, the exam performances for Teacher A increased from the first exam to the final exam, while the students enrolled in Teacher B and C resulted in decreased scores. The differences between the scores may be due to the final exams being cumulative. As a result, one could claim that the students for Teacher A better understood materials learned after the first exam compared to the other two instructors. The differences in exam scores by exam time and teacher indicates that these two constructs should be included in the linear mixed model as confounding variables.

Table 2.2

Descriptive Summary of Calibration, Mathematics Anxiety and Exam Performance

Construct	Exam	Teacher	*n*	*M*	*SD*
Calibration Accuracy	First	A	46	.20	.07
		B	43	.23	.07
		C	26	.25	.10
		Total	115	.22	.08
	Final	A	49	.19	.08
		B	46	.21	.07
		C	28	.21	.09
		Total	123	.20	.08
Calibration Bias	First	A	46	.03	.10
		B	43	-.10	.12
		C	26	-.05	.12
		Total	115	-.04	.12
	Final	A	49	-.01	.11
		B	46	.04	.11
		C	28	.10	.13
		Total	123	.03	.12
Mathematics Anxiety	First	A	51	27.18	6.57
		B	49	27.30	4.96
		C	28	27.34	4.87
		Total	128	27.08	5.45
	Final	A	46	26.21	6.24
		B	46	25.37	5.50
		C	27	24.87	4.64
		Total	119	25.57	5.60
Exam Performance	First	A	51	71.54	11.41
		B	48	83.74	14.07
		C	29	82.19	14.82
		Total	128	79.00	13.96
	Final	A	50	78.13	9.83
		B	48	76.58	10.59
		C	29	78.13	13.20
		Total	127	77.72	10.78

Correlational Analyses

Table 2.3 presents the zero-order correlations for calibration accuracy, calibration bias, mathematics anxiety and exam scores. The correlation between calibration accuracy and calibration bias was significant. Also, the correlations between the exam scores and the other three variables were significant. Mathematics anxiety was positively correlated to calibration accuracy at a weak level, while the exam scores were negatively correlated with calibration accuracy and bias at a moderate level and mathematics anxiety at a weak level. In other words, these correlations suggest that as students become better calibrated in terms of accuracy and lack of confidence, their exam scores increase. Additionally, as students become less math anxious, they become more overconfident and, as a result, do worse on the exams, which may be due to the negative effects of overconfidence on learning.

The relationship between mathematics anxiety and calibration was also examined to ensure that intrinsic aliasing was not an issue in the linear mixed model analysis. A linear mixed model with intrinsic aliasing issues would have some parameters in the model that could not be estimated using the data. Calibration bias was not significantly correlated to math anxiety, while calibration accuracy and math anxiety were significantly correlated. However, the significant correlation was weak, and as a consequence, there was no reason to exclude either variable due to intrinsic aliasing issues.

Table 2.3

Correlations Among Possible Continuous Fixed Effects and Dependent Variable

Measures	Calibration Bias	Math Anxiety	Exam Scores
Calibration Accuracy	-.04	.27*	-.45*
Calibration Bias	-	-.12	-.55*
Math Anxiety		-	-.29*
Exam Scores			-

*p < .01

Linear Mixed Model Analysis

The linear mixed model included the fixed effects, calibration accuracy, calibration bias, mathematics anxiety, teacher and time, and the random effect, participant. Given that a step-up strategy was implemented for determining the model, I started with model one, which included only the fixed effects. Every term in the model was significant, except for time, according to the Type III tests for fixed effects as seen in Table 2.4. As seen in Table 2.5, all the parameter estimates were significant except for time and the indicator variable for teacher B. Following the step-up strategy, I ran models which tested whether two-way interaction effects, made from the combinations of calibration accuracy, calibration bias, mathematics anxiety and teacher, were significant. Only one of the models, referred to as model two, resulted in a significant interaction effect, calibration bias cross teacher, as seen in Table 2.4. Table 2.5 shows that the parameters estimates for model two were all significant, except for time and calibration bias cross teacher B. Comparing the model fit statistics, Akaike information criterion (AIC) and Bayes information criterion (BIC), between model one (AIC = 1486.6, BIC =

1492.4) and two (AIC =1480.7, BIC = 1486.3), model two is a slightly better model. This along with the fact that the interaction effect was significant, model two was the best model according to the step-up strategy.

Table 2.4

Type III Tests of Fixed Effects for Model 1 and Model 2

	Model 1		Model 2	
Variables	Between-Group DF (Within-Group DF)	F Statistic	Between-Group DF (Within-Group DF)	F Statistic
Time	1 (102)	.40	1 (101)	1.85
Calibration Accuracy	1 (102)	68.41***	1 (101)	66.06***
Calibration Bias	1 (102)	314.86***	1 (101)	14.05**
Math Anxiety	1 (102)	21.12***	1 (101)	22.00***
Teacher	2 (102)	12.86***	2 (101)	29.24***
Calibration Bias*Teacher			2 (101)	6.97*

* $p < .01$, ** $p < .001$, *** $p < .0001$

Table 2.5

Linear Mixed Model Parameter Estimates for Model 1 and Model 2

	Model 1		Model 2	
Variable	Estimate	*SE*	Estimate	*SE*
Intercept	105.81***	2.86	105.55***	2.79
Time	-.44	.69	-1.39	.72
Calibration Accuracy	-52.93***	6.40	-53.62***	6.32
Calibration Bias	-60.33***	3.40	-66.23***	5.83
Math Anxiety	-.43***	.09	-.39***	.09
Teacher A	-7.64***	1.58	-8.18***	1.55
Teacher B	-2.88	1.58	-3.28*	1.54
Calibration Bias*Teacher A			28.24**	9.06
Calibration Bias*Teacher B			-2.96	7.03

* $p < .01$, ** $p < .001$, *** $p < .0001$

After checking that the assumptions of linear mixed models were satisfied for model two, I conducted influence diagnostics to identify any observations that heavily influenced the parameter estimates in the model as REML estimation methods are sensitive to unusual estimates. The influence diagnostics examined were the restricted likelihood distance, Cook's D for both fixed effects and covariance parameters, and covratio statistic for fixed effects and covariance parameters. The covratio statistic measures the change in the determinant of the covariance matrix of the estimates by deleting the *i*th observation. The restricted likelihood distance indicated that the four participants had very large influence on the model compared to other participants. In particular, all four participants had a large effect on fixed effects according to Cook's D, while the covratio statistics indicated that removing three of the four would increase the precision of the covariance parameter estimates. Three participants also had a large effect on the covariance parameter estimates and that the precision of those estimates would increase if the participants' data were removed from the data. Following West, et al.'s (2007) guidelines, the participants were removed and the step-up strategy was implemented again using the same covariance structure and estimation method.

The models and influence diagnostics were repeated three more times due to the fact that more participants needed to be removed; thus, two participants were removed the second time, three the third time, and one removed the fourth time. Each time, the best fit model was the model that had all the fixed effects and the interaction of calibration bias and teacher because all the terms were significant according to Type III tests for fixed effects and the model fit statistics were the lowest for this model compared to the other models. The Type III tests for fixed effects and parameter estimates for the final model are in Table 2.6 and Table 2.7, respectively. There were 111 participants remaining in the final model.

Table 2.6

Type III Tests of Fixed Effects for Final Model

Variables	Between-Group DF (Within-Group DF)	F Statistic
Time	1 (89)	.52
Calibration Accuracy	1 (89)	172.02**
Calibration Bias	1 (89)	398.33**
Math Anxiety	1 (89)	9.74*
Teacher	2 (89)	23.15**
Calibration Bias*Teacher	2 (89)	7.34*

* $p < .01$, ** $p < .0001$

Table 2.7

Linear Mixed Model Parameter Estimates for Final Model

Variable	Estimate	*SE*
Intercept	103.58**	1.97
Time	-.51	.71
Calibration Accuracy	-67.79**	5.17
Calibration Bias	-76.20**	5.75
Math Anxiety	-.22*	.07
Teacher A	-6.19*	.99
Teacher B	-1.60	.98
Calibration Bias*Teacher A	31.10**	8.12
Calibration Bias*Teacher B	15.06*	6.75

* $p < .01$, ** $p < .0001$

Accounting for any significance of each category, the final model is:

$$E_{ti} = 103.58 - .51 \times Time_{ti} - 6.19 \times TA_i - 67.79 \times C_{ti} - 76.20B_{ti} - .22 \times A_{ti} + 31.10B_{ti} * TA_i + 15.06B_{ti} * TB_i$$

where E_{ti} represents the exam scores taken on the *t*-th occasion for the *i*-th subject, $Time_{ti}$ represents the *t*-th time at which the *i*-th subject is measured, TA_i is an indicator variable that designates whether the i-th subject had Teacher A or not, C_{ti} represents the *t*-th calibration accuracy score at which the *i*-th subject is measured, B_{ti} represents the *t*-th calibration bias score at which the *i*-th subject is measured, A_{ti} represents the *t*-th mathematics anxiety at which the *i*-th subject is measured, $B_{ti} * TA_i$ represents the difference slope of calibration bias for Teacher A versus Teacher C, and $B_{ti} * TB_i$ represents the difference slope of calibration bias for Teacher B versus Teacher C. All the variables, except time and the indicator variable for teacher B, were significant predictors of mathematics exam performance. Even though time was not a significant predictor, time was kept in the model to account for the differences in the exams such as the number of problems, difference in content and length of time given for each exam. After verifying that the assumptions were satisfied and investigating that there were no more participants that largely affected the parameter estimates using influence diagnostics, the least-square means were estimated from the linear mixed model and post-hoc comparisons of them were conducted using the Tukey-Kramer adjustment method to compare the different levels of the teacher variable. As seen in Table 2.8, the estimated exam mean for Teacher A is lower than Teacher B and Teacher C. The post-hoc indicated that Teacher A had significantly lower exam scores than Teachers B and C.

This was similar to one of the main effects of teacher; in particular, the comparison of Teacher B and Teacher C in the model, which was not significant.

Table 2.8

Least Square Means of Exam Scores for Teacher

Teacher	Exam Estimate	*SE*
A	77.65	.61
B	82.23	.61
C	83.82	.77

Given the interaction between calibration bias and teacher, the interpretation of calibration bias's influence on exam performance differs by teacher, while the other main effects in the model do not depend on teacher. The model indicates that as participants' calibration accuracy scores decrease by .05 (or the difference between perceived and actual performance decreases by 5 points on a 100-point exam), their exam scores increases by 3.39%. Also, as the participants' mathematics anxiety increases by 1, their exam scores decrease by .22%; hence, as pre-service elementary teachers become more mathematics anxious, their exam scores decrease slightly. As participants' calibration bias decrease by .05 (or their confidence decreases by 5 points on a 100-point exam), their exam scores increase by 2.26% for Teacher A, by 3.06% for Teacher B, and by 3.81% for Teacher C.

Discussion

Within this study, I investigated the association between calibration, mathematics anxiety and mathematics achievement at the college level. This was accomplished by focusing on an important population, pre-service elementary teachers, to answer the research question: Does calibration and mathematics anxiety significantly predict mathematics exam performance in pre-service elementary teachers accounting for instructors? To answer this question, correlational and linear mixed model analyses were conducted. The correlational analysis indicated that calibration prediction accuracy significantly correlated with mathematics anxiety, while calibration bias did not. The linear mixed model analysis indicated that mathematics anxiety and calibration were significant predictors of mathematics exam performance, but in unexpected ways. In particular, the change in mathematics anxiety leads to a weak change in exam performance, and calibration bias interacted with teacher. In the following sections, I discuss the pairwise relationships between calibration, mathematics anxiety and mathematics achievement in terms of the meaning of the findings and their importance followed by the limitations and implications of this study.

Calibration and Mathematics Achievement

The correlational analysis shows that calibration bias and accuracy were significantly negatively correlated to exam performance at a moderate level. In other words, these correlations suggest that as students become better calibrated in terms of accuracy and more underconfident, their exam scores increase. The linear mixed model analysis illustrates a similar influence of calibration accuracy and bias on mathematics exam performance. In particular, the main effect of calibration accuracy was significant, but also the two-way interaction effect of calibration bias and teacher was significant.

Previous K-12 research has found similar correlational results for calibration accuracy (e.g., Ozsoy, 2012) and calibration bias (e.g., Chen, 2003; Chen & Zimmerman, 2007) with the correlation coefficient for calibration accuracy ranging between .6 and .9, and the coefficient for bias ranging from -.4 to -.7. Keep in mind that the calibration accuracy for this study has lower values representing better accuracy, while other researchers tend to use higher values to represent better accuracy. In other words, other researchers use zero to represent someone who is completely not calibrated and one to represent someone who is perfectly calibrated. Because the calibration accuracy and mathematics performance correlation in this study was $r = -.45$, this suggests that calibration accuracy is not as important to success on an exam as it is in grades K-12. Also, given that the correlation between bias and performance is higher than accuracy and performance, and the influence of bias is larger than accuracy for at least one teacher, the students' level of confidence seems to be more important than how accurately their confidence matches their ability. This may be because reducing participants' confidence would cause them to study more (Hacker et al., 2008b; Nelson & Narens, 1990). They might end up spending time studying material they already know; however, they would also spend time studying material that they do not know well enough. Even though their study time may not be spent efficiently, their knowledge would increase and provide them better academic success in class and on the exams. These findings indicate that the overall same pattern observed in K-12 calibration and mathematics achievement research holds for pre-service elementary teachers and possibly could hold for undergraduates in general with some slight differences.

The significant interaction between calibration bias and teacher in the linear mixed model indicates that the type of teacher can influence the link between calibration bias and mathematics achievement for pre-service elementary teachers. The course that pre-service elementary teachers took was coordinated. All three instructors covered the same topics and activities, taught in social constructivist manner, had classrooms with hexagon tables for group work, and tested the same material. The only difference in the exams was the scenarios for a couple of problems were tweaked to fit the instructor, but the problems still tested the same topics as the original version of the problems. Hence, the difference in the influence of calibration bias on exam performance does not relate much to the course itself, but the type of teacher students had.

The type of teacher influences the implementation of the social constructivist approach, interaction with the students, and the type of feedback given to the students on presentations, assignments and assessments. As mentioned in the literature review of calibration and mathematics achievement, some researchers (Hacker et al., 2000; Labuhn et al., 2010; Nietfeld et al., 2006) have found certain types of feedback causes students to have better calibration accuracy and less calibration bias, while others (Nietfeld, et al., 2005; Schraw et al., 1993) found that feedback does not improve calibration. Also, Gutierrez and Price (2017) suggested that group work and, in particular, the social interactions within the group can improve students' calibration. Because the teacher determines what feedback to provide to students and helps shape how groups conduct themselves during group work, the teacher can influence students' calibration and, in turn, their achievement. Additionally, for the pre-service elementary teachers in this study, the type of teacher has more influence over calibration bias than accuracy.

Calibration and Mathematics Anxiety

In this study, calibration and mathematics anxiety are weakly correlated with only accuracy and anxiety being significantly correlated, while the linear mixed model analysis showed that the interaction terms between mathematics anxiety and calibration were not significant. The correlations between calibration and mathematics anxiety suggest that as students became more anxious, they became less accurate in their calibration and more overconfident. The indicated relationship between calibration and mathematics anxiety fit within Van Overschelde's (2008) extension of Nelson and Narens's (1990) metacognition model.

Mathematics anxiety can affect students' self-regulated learning through their metacognitive monitoring and control. For metacognitive monitoring, mathematics anxiety can lower the confidence people have when studying because mathematics anxiety and measures of confidence have been found to be inversely correlated (e.g., Jameson & Fusco, 2014; Legg & Locker, 2009; Malpass et al., 1999). This, in turn, may cause them to study topics more than they need to for an exam. For metacognitive control, mathematics anxiety as an internal perceived constraint limits what control actions a person can use when studying and attempting to solve problems. This could cause students to not study appropriately and/or effectively, and to fail to solve problems even though they may possess the knowledge and ability to do so. Additionally, mathematics anxiety can inhibit metacognitive monitoring when a student attempts to solve a mathematics problem by limiting the amount of information that be contained in working memory (Ashcraft, 2002; Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Raghubar et al., 2010).

When students attempt to calibrate, the amount of problem information that can be stored in working memory is subdued by mathematics anxiety; thus, the problem in working memory may not possess all the vital information and maybe some superfluous information to solve the problem and, as a result, can cause students to make their calibration judgment within the metacognitive model using an incomplete picture. This can cause the students to be less accurate in their calibration. What was surprising with these results was that calibration bias and mathematics anxiety were not significantly correlated. However, this may be due to measuring mathematics anxiety a class or two before calibration. Researchers in other studies have conducted the anxiety surveys at the time of their other measurements. As a consequence of this difference, calibration and mathematics anxiety might have a stronger relationship than indicated in this study.

Mathematics Anxiety and Achievement

Mathematics anxiety was weakly, but significantly correlated to exam performance. The linear mixed model also indicated this with a significant main effect of mathematics anxiety on performance. These together indicate that as students become more math anxious, their exam performance decrease, which previous research (e.g., Andrews & Brown, 2015; Hembree, 1990) has already found. The overall effect of mathematics anxiety on performance was a 6.6% increase in exam performance from the highest mathematics anxiety to the lowest mathematics anxiety on the survey, which was similar to the influence that mathematics anxiety had on mathematics performance for Legg and Locker’s (2009) participants. Even though mathematics anxiety can influence self-regulated learning for pre-service elementary teachers through the inhibition of metacognitive monitoring and control during studying, and mathematics anxiety tends to be higher in pre-service elementary teachers, the impact seems to be limited compared to other constructs’ direct influence on mathematics exam performance. However, mathematics anxiety is still important to performance due to the influence mathematics anxiety has on other constructs that are also related to performance (Chang & Beilock, 2016). The limited impact of mathematics anxiety in this study may be due to the timing of the math anxiety measurement, as mentioned earlier.

Implications

Based on the findings and limitations of this study, there are several implications for educational practices and research. An educational implication is to advocate for calibration training in the classroom. Kruger and Dunning (1999) found evidence that improving students' calibration ability would help them recognize the limitations of their abilities and knowledge. The benefit of improving calibration was greater for the lower achieving students as they tended to make poor decisions and did not have the metacognitive abilities to recognize it. Furthermore, Cardelle-Elawar (1995) and Kramarski and Mevarech (2003) proposed that metacognitive training, which are the skills necessary for calibration, in mathematical context is beneficial to students' performance. Cardelle-Elawar (1995) examined low math achieving students in third to eighth grade by randomly assigning them to a traditional instruction or a metacognitive training instruction. The students who received metacognitive training answered questions throughout the problem-solving process that related to functions of metacognition such as whether they understood what the problem was asking and what operations that were needed to solve a problem did the student have difficulty completing. Kramarski and Mevarech (2003) investigated whether the IMPROVE method, which focused on improving students' metacognitive abilities, helped eighth and ninth graders with their performance. Both found that those who received metacognitive training significantly improve their math performance compared to the traditionally taught students.

One method to improve students' calibration, besides aforementioned metacognitive training, may be to provide students with an opportunity to practice calibration through the course along with feedback to allow them to self-reflect on their knowledge and calibration. Nietfeld et al. (2006) found weekly monitoring practice on quizzes with feedback caused students to become better calibrated. However, some researchers (e.g., Schraw et al., 1993) suggest that feedback does not help student calibrate. This may be due to whether students used the feedback to self-reflect or not because DiGiacomo and Chen (2016), Ramdass and Zimmerman (2008) and Zimmerman et al. (2011) found that self-reflections improve students' calibration and, in turn, their performance. Also, it may be due to the nature of the feedback as Labuhn et al. (2010) suggested that certain types of feedback are more useful for improving calibration. Thus, researchers should investigate the different types of feedback that teachers provide to determine what would improve calibration along with what self-reflection students utilize with that feedback.

Another future research investigation could explore the characteristics of teachers and/or different instruction methods in relation to calibration. In particular, the relationship between teacher and calibration found in this study needs to be further verified with the pre-service elementary teacher population along with whether teacher and/or instruction method affects calibration in other mathematics populations and ages. It might be possible that teachers may not be able to help students directly with their calibration accuracy without the methods described by Cardelle-Elawar (1995) and Kramarski and Mevarech (2003), and that I suggested previously. However, teachers may be able to help students become less biased or at least overconfident based on their feedback to students (Hacker et al., 2000; Labuhn et al., 2010; Nietfeld et al., 2006) and emphasizing group work with appropriate discussions with and between students (Gutierrez & Price, 2017). By becoming less biased, students may then become more accurate in their calibration.

Due to the lack of extensive research and the suggestion of Chang and Beilock (2016) on further investigation of factors that may affect the link between mathematics anxiety and achievement, another future research study could be to conduct further research on the connection between mathematics anxiety and calibration. For example, how mathematics anxiety inhibits students' calibration prediction and postdiction judgments and, in turn, their calibration accuracy and bias through the examination of working memory and the limitations caused by mathematics anxiety. Also, researchers could investigate whether mathematics anxiety moderates the relationship between calibration and mathematics performance, or calibration moderates the relationship between mathematics anxiety and performance - the literature suggests the former option (Chen, 2003; Malpass et al., 1999). I believe the latter is more likely because of mathematics anxiety's influence on students' self-regulated learning and attempts at calibrating for an exam using their working memory in conjunction with their metacognitive monitoring and control.

Limitations

There were several limitations of this study, which involved the time-frame during which the mathematics anxiety was measured, the format of the self-efficacy survey, and the calibration calculation. Mathematics anxiety was measured one or two class days before, or five or seven days before, the exams. Consequently, mathematics anxiety in this study may not represent the mathematics anxiety the students had when taking the test. One reason for this is due to several students mentioning that they had not yet studied for the test when they were handing in the mathematics anxiety survey. Those that had not studied may not have known what they knew or did not know of the material for the test. By the time they took the exam, their mathematics anxiety could have changed depending on how well they learned the material. Hence, the relationship between mathematics anxiety and other constructs in this study may be smaller than they would have been otherwise. The reason mathematics anxiety had to be measured at this time, instead of the day of the exam, was due to concern from the mathematics coordinator and instructors of the pre-service elementary teacher course. They felt that measuring mathematics anxiety right before the exams would cause students to more actively think about their mathematics anxiety when taking the exams and, as a result, lead them to perform worse on the exams.

The response format of the self-efficacy surveys could influence students' ability to judge their performance as well. Each item on the surveys provided the students with a problem from the exam along with the point value of the problem, and then asked the student to fill in the blank in the sentence: "I will receive ____ points on this problem." An issue with this design was that some students may not have understood how much a problem was worth due to misreading the point value. There is evidence that some students had this issue when it came to problems on the exams that mentioned how much each part of the problem was worth instead of how much the problem was worth overall. Their self-efficacy scores and, consequently, their calibration accuracy and bias may not represent what the students intended; thus, the students would seem more underconfident and less accurate in their calibration. One method that could fix this issue is to include the blank sentence for each item that indicates how many points each item is worth in total. Another way is to put the blank sentence under each part of the problem after changing it to ask how many points the student would get for each part of the problem.

Another issue related to the format of the self-efficacy survey is how confidence is measured. Instead of utilizing a confident judgment using a 10-point or 100-point scale, or confidence line as suggested by Hacker et al. (2008b), students used point values to determine their confidence due to the nature of the exam problems and to have students account for how they believed their teacher grade those problems. Most exam questions were open-ended with a couple of matching problems. Open-ended questions make it hard to determine what a certain level of confidence means compared to point values. For example, if students determine that they are 80% confident on a problem, what does that mean in terms of point values when the problem is worth ten points? This does not necessarily mean they believe they would receive eight points as it depends on which parts of the problem they believe they can do and how much those parts are worth pointwise to the instructor. Thus, students were asked to take an additional step, and use their confidence and knowledge of their instructor to determine how many points they would get per problem as this is more aligned with their current thoughts when it comes to success on an exam. Even though this does not follow the standard convention described by Hacker et al. (2008b) for calculating calibration accuracy and bias, Alexander (2013) mentioned that there is no standard way to collect calibration judgments and to calculate calibration. Therefore, the current findings related to calibration may not generalize to other calibration prediction surveys, nor to other calibration accuracy and bias findings.

Conclusion

This study is an initial attempt to investigate the relationship between calibration, mathematics anxiety and achievement. In particular, the collective impact of calibration and mathematics anxiety on achievement was examined. For pre-service elementary teachers, calibration and mathematics anxiety significantly correlated with exam performance, while only calibration accuracy significantly correlated with mathematics anxiety. In the linear mixed model, teacher, calibration accuracy, calibration bias and mathematics anxiety were significant predictors along with the two-way interaction of calibration bias and teacher, while the interactions between calibration and mathematics anxiety was not. These results indicate that there are other constructs in mathematics education that may influence the link between calibration and mathematics achievement. The findings in the mathematics education literature also hold for the pre-service elementary teacher population. Additionally, more research needs to be conducted to examine the relationship between mathematics anxiety and calibration, and how students can improve their calibration and accordingly, their achievement in the classroom

CHAPTER III

THE RELATIONSHIP BETWEEN CALIBRATION, MATHEMATICS ANXIETY AND ACHIEVEMENT OF OFF-TRACK PRE-SERVICE ELEMENTARY TEACHERS

Introduction

Suppose that a student is preparing for an algebra exam that will happen in two days. With only a couple of days left to study, how will the student focus his/her studying of the topics? No matter what study strategy is utilized, the most effective studying occurs when students can accurately judge their current understanding of the possible test topics (Gutierrez & Price, 2017). For example, a student studying algebra may judge that the topic of multiplying binomials and factoring trinomials are learned well enough for the test, while the topic of solving a quadratic function is not mastered yet. The student knows to spend more time studying how to solve quadratic functions, while maybe briefly reviewing multiplying binomials and factoring trinomials. The metacognitive monitoring and control processes students goes through when accurately determining what they know and do not know during studying allow the student to focus their attention and cognitive resources on topics not yet mastered, while spending less time on known topics (Hacker et al., 2008b). Additionally, due to a shift from teacher-centered to student-centered teaching practices, students have been increasingly required to accurately monitor and control their learning (Kostons & de Koning, 2017).

Calibration of performance is an important construct within metacognitive monitoring that allows for such actions in the previous scenario to occur. Calibration is defined as the degree to which a person's perceived performance on a task matches to his or her actual performance on that task (Hacker et al., 2008b; Nietfeld et al., 2006). Accurate calibration allows students to know exactly what they need to study, for example to be better prepared for an exam, while inaccurate calibration causes students to spend too much time studying material they already know or not enough time on material they do not know (Hacker et al., 2008b; Stone, 2000). This may be why many studies have found that calibration positively correlates with achievement (e.g., Chen & Zimmerman, 2007; Hacker, Bol, & Bahbahani, 2008a; Ozsoy, 2012).

Another research construct that affects mathematics achievement is mathematics anxiety. Chang and Beilock (2016) provided a review of the existing studies investigating the link between mathematics anxiety and achievement, and suggested that further investigation into factors that explain the relationship between mathematics anxiety and achievement could provide valuable insight for improving mathematics performance. Herts and Beilock (2017) expand upon this by mentioning that "a considerable amount is known about how anxiety influences students' performance on tests, but far less is known about how anxiety may influence learning in the first place" which is vital as "[t]his connection could have important implications in the classroom" (p. 723). Legg and Locker (2009) found that certain metacognitive skills that are important during learning process, such as planning, checking, monitoring and evaluating behaviors during a task, moderated the link between mathematics anxiety and performance. According to Nelson and Narens's (1990, 1994) metacognitive model along with Van Overschelde's (2008) extension, this result indicates that mathematics anxiety could inhibit the usage of metacognitive skills involved in students' calibration of performance judgements. Following Legg and Locker's (2009) suggestion that further research needs to be done to understand the relationship between metacognition and mathematics anxiety, the present study examined the relationship between mathematics anxiety, calibration and mathematics achievement of pre-service elementary teachers.

Literature Review

Theoretical Framework for Calibration

The importance of metacognition in learning has been emphasized by researchers over the years (e.g., Kramarski & Mevarech, 2003; Schoenfeld, 1983; Veenman et al., 2006). The existing research studies on metacognition and learning tend to focus on the domain of psychology and English with a few studies in mathematics. Those studies in mathematics mainly focused on elementary and middle school students (e.g., Bol, Riggs, Hacker, Dickerson, & Nunnery, 2010; DiGiacomo & Chen, 2016; Gutierrez de Blume, 2017) with sparse amount of them having participants at tertiary level (e.g., Champion, 2010; Gutierrez & Price, 2017). In addition, most of these metacognitive studies were conducted in experimental laboratory setting. Hacker et al. (2008b), and Nelson and Narens (1994) argued that part of the reason that metacognition research lack cumulative progress is partly due to researchers attempting to control variations in participants' cognition in laboratory settings. Hacker et al. argued that researchers need to leave the laboratory and enter more valid environmental conditions such as the classroom.

To further the study of metacognition outside the laboratory setting and expand upon Nelson and Narens's (1994) sentiment, Hacker et al. (2008b) suggested studying calibration, a construct of metacognition, in the classroom setting. In particular, they noticed the need to study calibration in the classroom because calibration used in studying and taking exams in a classroom setting has different underlying motivations, goals, and constraints for students than calibration in a laboratory study. This is in part due to the particular course a student is taking, the positive and negative emotions the student brings into and elicits by the course, and the effect that exams has on their course grade. Thus, studying calibration in the classroom setting is also related to students' self-regulation learning process. The self-regulated learning can be defined through several differing metacognitive models. The metacognitive and self-regulated learning model utilized for this study is Nelson and Narens's (1990,1994) model, which was expanded upon by Van Overschelde (2008).

Nelson and Narens's (1990) model has two levels for mental processes, an object-level and meta-level. The object-level in this model refers to a person's cognition during a task. The meta-level contains a dynamic model of the object-level, which students can manipulate to better understand the object-level. Metacognitive monitoring is the flow of information from the object-level to the meta-level that affects the dynamic model. Metacognitive control is the flow of information from the meta-level to the object-level that affects the actions occurring at the object-level. During the monitoring process, students judge how well they are doing based on the information at the object-level, while students use that judgment along with their meta-level knowledge, strategies, and goals to determine what actions to perform at the object-level during the control process.

Nelson and Narens's (1990, 1994) model was expanded upon by Van Overschelde (2008). He discussed some additional components at the meta-level that he believed was implied in Nelson and Narens's work. A component of interest is the perceived constraints students can have when preparing for a test. During metacognitive control, a student's perceived constraints limit their actions. Perceived constraints include internal forces such as expectations of and motivations for a class and exams, and external forces such as time limits for studying and taking exams. This additional component discussed by Van Overschelde assists in explaining why students can make different decisions when regulating their studying under similar meta-level and metacognitive monitoring circumstances. Additionally, students' perceived constraints can influence their calibration in the classroom.

Hacker et al. (2008b) discussed Nelson and Narens's (1990, 1994) memory stages framework and the placement of calibration within it. Calibration judgments occur after acquisition and retention, but may be made either before or after the retrieval of relevant knowledge. *Prediction calibration judgments* refer to judgements made before retrieval, while *postdiction calibration judgments* are the judgments that occur after retrieval. Hacker et al. believed that prediction judgments are made when students monitor their knowledge before the retrieval of knowledge. On the other hand, Koriat et al. (2006) suggested that those judgments occur during or after the self-direct search phase within the retrieval stage as metacognitive monitoring and control are ongoing and mutually informing processes. Hacker et al. stated that postdiction judgments are similar to Nelson and Narens's confidence judgments and come after recall. For the present study, Koriat et al.'s approach to prediction judgments and Hacker et al.'s view of postdiction judgments were assumed to be utilized by students when asked to calibrate before and after the exams.

Calibration plays an important role in self-regulated learning by providing information to a student about what has been studied well enough or needs additional studying. Also, accurate calibration provides a better chance of triggering control actions that further help a student's learning. In particular, it can affect the control actions that a student uses when studying, for example, continuing with a particular strategy, focusing on certain parts of a concept, or approaching a problem in a different way to try to fix some insufficiencies of a previous approach. These control actions depend on the prediction or postdiction calibration judgments a student utilizes when solving a problem or testing their knowledge. These judgments can be used to calculate calibration measurements. In this study, calibration accuracy and calibration bias were calculated at two levels: global (i.e., for the whole test) and local (i.e., for each question on a test) at two different times, before working on the test (prediction) and after working on the test but before seeing the instructor's grading (postdiction). Calibration accuracy measures the degree to which a person's belief of ability (i.e., self-efficacy) to perform a task corresponds to his/her performance on that task, while calibration bias indicates whether a student under- or overestimates his/her ability and by how much (Bol, Hacker, Walck, & Nunnery, 2012; Keren, 1991; Nietfeld et al., 2005; Zimmerman & Moylan, 2009). Global calibration examines calibration accuracy and bias at the level of the whole exam, while the level for local calibration is each question on the exam. Hacker et al. (2008b), and Ramdass and Zimmerman (2008) discussed that overconfidence, underconfidence, and level of inaccurate judgments of one's capabilities can harm one's learning and motivation in mathematics. If students overestimate their ability, then control actions necessary for the student to attain better understanding of a topic might fail to trigger and cause no changes to their studying strategies and learning processes. If students underestimate their ability, then the students might spend more time than necessary studying a topic when in fact they understand enough of the material for their course. Both scenarios can cause the students to not be prepared for their class and lead to future unnecessary struggles with the course content.

Relationship Between Calibration and Mathematics Achievement

Calibration has been examined and measured in multiple ways throughout the years (Alexander, 2013). The two most common methods of examining calibration are through calibration accuracy and bias (Hacker et al., 2008b), or sensitivity and specificity (Rutherford, 2017). Accuracy and bias was utilized in the present study as these two measurements have been utilized more frequently with relation to achievement. The association between calibration and achievement has been examined in many different domain areas: biology (e.g., Bol et al., 2012), computer games (e.g., Nietfeld et al., 2013), psychology (e.g., Hacker et al., 2008a), reading (e.g., Singer & Alexander, 2017), and research methods (e.g., Bol & Hacker, 2001). These studies generally indicated that better calibrated students have better achievement.

Research studies that are done on calibration and achievement in mathematics have found the two constructs to be significantly correlated at the moderate or strong level (Chen, 2003; Chen & Zimmerman, 2007; Garcia et al., 2016). The correlations indicated that local prediction (before working on the test) and postdiction (after working on the test) calibration accuracy positively correlated with performance, while their biases negatively correlated with performance. In other words, as students become more accurate with their calibration, and less confident (i.e., the bias score is getting closer to negative one) in their mathematics ability and knowledge, their mathematics performance becomes better. The negative correlation between bias and performance has appeared in a number of studies and is referred to as underestimation bias (Pajares, 1996; Stone, 2000). Another common pattern for bias is that students tend to be overconfident in their mathematical capability when attempting to calibrate (Dinsmore & Parkinson, 2013; Pajares & Kranzler, 1995; Pajares & Miller, 1994). Other researchers have found evidence that supports these patterns through comparisons of exam types (e.g., Pajares & Miller, 1997), longitudinal studies (e.g., Rinne & Mazzocco, 2014; Sheldrake et al., 2014), self-regulated learning interventions (e.g. Chen, Cleary, & Lui, 2015; DiGiacomo & Chen, 2016; Gutierrez de Blume, 2017), gifted versus non-gifted comparisons (e.g., Pajares, 1996), and feedback type comparisons (Labuhn et al., 2010).

Additionally, Chen (2003) conducted a path analysis on calibration, performance and other possibly related constructs. She found that calibration accuracy had an overall positive effect on mathematics performance, and prior mathematics achievement had an indirect effect on mathematics performance which was mediated by calibration accuracy. Jacobse and Harskamp (2012) found a similar effect of calibration on mathematics achievement due to calibration accuracy explaining 16% to 36% of the variance of mathematics achievement. Stankov et al. (2012) indicated that calibration bias can influence mathematics achievement in their correlational and multiple regression analyses, while Freeman, Karayanidis and Chalmers (2017) found that calibration bias was the best metacognitive monitoring measurement for predicting mathematics achievement.

Relationship Between Mathematics Anxiety and Achievement

The connection between mathematics anxiety and achievement over the last 60 years has been an important area of research (Herts & Beilock, 2017). One of the key reasons for this has been due to the negative effect of mathematics anxiety on mathematics performance (Andrews & Brown, 2015; Cargnelutti, Tomasetto, & Passolunghi, 2017; Hembree, 1990; Klados, Pandria, Micheloyannis, Margulies, & Bamidis, 2017). Additionally, higher math-anxious students tend to avoid mathematics, and take fewer mathematics courses in secondary and tertiary levels (Hembree, 1990), which leads students to avoid careers in the fields related to science, technology, engineering and mathematics (Foley et al., 2017). For pre-service teachers, their mathematics anxiety can negatively influence their belief in their ability to teach mathematics (Cook, 2017), and their future students' mathematical attitudes and ability (Beilock et al., 2010).

Some research has investigated the influence of mathematics anxiety on mathematics achievement and the possible factors that assist in the understanding of their relationship with each other (e.g., Klados et al., 2017; Lukowski et al., 2016). For example, the Organization for Economic Cooperation and Development's (OECD, 2013) report on the 2012 Program for International Student Assessment (PISA) indicated that higher math-anxious students showed lower levels of mathematics performance than lower math anxious students in 63 of the 64 educational systems, which also held for the highest performing students when controlling for gender and socioeconomic status.

An important factor that has been examined for mediating the relationship between mathematics anxiety and achievement is the working memory. Ashcraft and

Kirk (2001) demonstrated mathematics anxiety can hinder working memory and, as a result, negatively affects mathematics performance. Beilock and Carr (2005), Justicia-Galiano, Martin-Puga, Linares and Pelegrina (2017), Novak and Tassell (2017), and Raghubar et al. (2010) investigated how working memory affects the link between mathematics anxiety and achievement. They showed that mathematics anxiety can exhaust resources in working memory, which, in turn, obstructs mathematical learning necessary for successful mathematics achievement. Additionally, students with the highest capacity for working memory had the strongest negative connection between mathematics anxiety and achievement (Beilock & Carr, 2005; Ramirez et al., 2013; Vukovic et al., 2013).

Chang and Beilock (2016) summarized research about factors that influence and/or mediate the link, which included working memory. They split the factors into two groups, individual and environmental, which were further divided into categories. The individual factors were split into cognitive, affective/physiological, and motivational domains. Cognitive factors that mediate the mathematics anxiety and achievement relation were working memory, retrieval-based strategy usage, and attention to details when solving problems. Affective/physiological factors encompassed bodily functions that corresponded with increased mathematics anxiety. This included increased cardiovascular activity, salivary cortisol concentration and brain activity in regions associated with pain perception and negative emotional processing. Motivational factors utilized intrinsic and external motivation to allow individuals to actively approach the mathematics at hand, and to decrease the avoidance of mathematical situations. The environmental factors were separated into teachers' mathematics anxiety and classroom activities, parents' mathematics anxiety, support and expectations, and students' perception of their classroom environment, respectively. These factors help explain how mathematics anxiety develops and how mathematics anxiety relates to mathematics performance. An example of an environmental factor that has been recently investigated was time given for a test. Hunt and Sandhu (2017) found that mathematics anxiety interacts with time pressure, which then influences mathematics performance, while Grays et al. (2017) indicated that explicitly telling students time mediates the relationship between mathematics anxiety and achievement by increasing the performance for low and medium anxious students more than the highly anxious students.

Mathematics anxiety research has also focused on a particular population of interest in this study, pre-service elementary teachers. A couple of reasons for this attention is that they will be the ones who most probably introduce the formal mathematical environment to the pupils. And, unfortunately, mathematics anxiety in pre-service elementary teachers is more common and prevalent than in other undergraduate populations (Baloglu & Kocak, 2006; Bessant, 1995; Hembree, 1990; Kelly & Tomhave, 1985; Novak & Tassell, 2017). This anxiety can have severe consequences on the students' mathematical learning such as teachers' mathematics anxiety can be transferred to their students and results in lower mathematics performance in students (Beilock et al., 2010; Gunderson et al., 2012; Jackson & Leffingwell, 1999).

Several factors that influence the link between mathematics anxiety and achievement for pre-service elementary teachers include family's mathematical history (Trujillo & Hadfield, 1999; Unglaub, 1997), mathematics teaching methods used by previous teachers (Brady & Bowd, 2005; Harper & Daane, 1998; Unglaub, 1997), negative experiences in mathematics classes (Bekdemir, 2010; Harper & Daane, 1998; Trujillo & Hadfield, 1999; Uusimaki & Nason, 2004), and students' negative experiences with current mathematics teachers (Brady & Bowd, 2005; Harper & Daane, 1998; Unglaub, 1997). Harper and Daane (1998) found additional factors that influenced mathematics anxiety such as working with word problems, an emphasis on the right answers and the right methods of solving the problem, fear of making mistakes, frustration at the amount of time it took to do word problems, an emphasis on time tests, feeling dumb when unable to solve a mathematics problem, and having no confidence in their mathematics ability. Lorenzen (2017) found that additional factors relating to the structure, content and student behavior in students' current mathematical course influenced their mathematics anxiety and achievement.

Research Purpose and Questions

The aim of this study is to investigate three facets of calibration in mathematics classroom that have not been explored in depth. First, previous mathematics education studies focused on calibration at the elementary and secondary grades. Only two studies have been found that investigate calibration in mathematics at the collegiate level. Champion (2010) examined the influence of calibration on achievement in students enrolled in mathematics courses for pre-service secondary teachers. Thanheiser (2018) examined the influence of an interview, designed to help pre-service elementary teachers better calibrate their knowledge, on their learning of mathematics. This study is important as pre-service elementary teachers need to understand their own existing content knowledge before teaching K-6 students (Adler & Ball, 2008; Pintrich, 2002; Thanheiser, 2018). Not knowing what they know, they may not be prepared well enough to teach certain mathematical topics and not realize that they need to do more preparation until it is too late. These gaps in knowledge of teachers may affect the children's belief in the teacher and, in turn, their understanding of mathematics. Additionally, development of pre-service elementary teachers' self-learning skills would benefit them as content and pedagogical content knowledge intertwines when they teach a topic in that content area to children (Ball et al., 2008; Hill et al., 2005).

Second, even though calibration and mathematics anxiety affect achievement individually, no research has been found to examine the relationship between all three of them. Some calibration research and mathematics anxiety research indicated that calibration could influence mathematics anxiety and, as a result, influence mathematics achievement; in particular, a student becoming better calibrated also becomes more mathematics anxious, (Chen, 2003; Malpass et al., 1999; Meece et al., 1990; Pajares, 1996; Pajares & Kranzler, 1995). This is due to students becoming better calibrated leading to less confidence as students tend to be overconfident in their mathematical abilities and knowledge, and the decrease in confidence increases their mathematics anxiety. Legg and Locker (2009) found that metacognition skills mediated the link between mathematics anxiety and achievement; in particular, individuals performed worse as their metacognition ability (planning, checking, monitoring, and evaluating) decreases at high levels of mathematics anxiety. However, math performance did not differ at low levels of mathematics anxiety regardless of metacognition skills. This indicates that calibration could mediate the relationship between mathematics anxiety and achievement as monitoring and evaluating are key metacognitive skills needed for students to calibrate. However, the overall influence of the relationship between calibration and mathematics anxiety having a positive or negative influence on mathematics achievement is unknown as calibration generally has a positive influence on mathematics achievement, while mathematics anxiety has a negative influence on achievement.

Lastly, calibration research in mathematics has not focused on global calibration. Most calibration studies tended to focus on calibration at the local level. Nietfeld et al. (2005) found that students were more accurate in their global calibration than local calibration; although, local calibration accuracy was related to performance in a psychology class. This indicates that global and local calibration might be related differently to mathematics anxiety and achievement. As such, to better understand the relationship between calibration and mathematics anxiety, and their relationship with mathematics achievement, global calibration was included in the study.

This study is designed to contribute to the existing literature by examining the relationship between calibration, mathematics anxiety and achievement among a sample of pre-service elementary teachers in two mathematics content courses. In particular, this study was conducted to implement the suggestions from Chang and Beilock (2016), Herts and Beilock (2017) and Legg and Locker (2009) as well as to address the need to expand the small number of studies in the domain of calibration in mathematics, by addressing the following research questions:

Q1 Is the change in mathematics anxiety of underconfident pre-service elementary teachers statistically significantly different from the change in mathematics anxiety of overconfident teachers accounting for instructor?

Q2 Does calibration statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q3 Does the change in mathematics anxiety statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q4 Does calibration and mathematics anxiety predict final exam performance accounting for instructor?

Method

Sample

Participants were 142 undergraduate students enrolled in the first and third mathematics content courses for pre-service elementary teachers in a required three-course sequence in a 15-week semester during the spring of 2017. Institutional Review Board (IRB) approval and consent form for this study can be found in Appendix F and G, respectively. The courses were taught in the mathematics department at four-year doctoral granting institution in the Rocky Mountain region. Table 3.1 summarizes the number of freshmen, sophomores, juniors and seniors enrolled in each of the courses. Most of the freshmen were in the first course, while most of the sophomores, juniors and seniors were in the third course. This was typical as the elementary education students at this university are encouraged to take their mathematics courses starting their first semester. Most of the participants were female (88.02%) and white (66.67%), which was typical for these courses at this university.

Table 3.1

Grade Level by Course

Grade Level	First Course	Third Course
Freshman	40	8
Sophomore	9	32
Junior	5	33
Seniors	1	9
Unknown	4	1

The first course focused on the real number system and arithmetic operations through examining the structure and subsets of real numbers using patterns, relationships, and properties. The third course focused on spatial reasoning in geometry and measurement through examination of two- and three-dimensional shapes, and their properties, measurements, constructions and transformations. For both of these courses, students met twice a week for 75 minutes and mostly worked in groups. Even though the courses are primarily for elementary education students, students majoring in special education who focus on K-3 or K-12 education were required to take the first course along with early childhood education majors who focus on K-3 education.

Table 3.2 summarizes the number of participants majoring in early childhood education, elementary education, and special education along with concentration areas of the elementary education participants. Some students were counted twice in the table as some of them had dual majors or dual concentration areas. About half of the participants (52.11%) were elementary education majors and 32 (22.53%) majored in only special education, while 13 (9.15%) were both elementary and special education majors. The information from Tables 3.1 and 3.2 were obtained from a demographics survey (Appendix H).

Table 3.2

Majors and Concentration Areas of the Participants

Major	Concentration Area	Participants (N=142)
Early Childhood Education		16
Elementary Education	Biology	5
	Chemistry	2
	Civics (Political Science)	1
	Creative Drama	1
	Cultural and Linguistic Diversity	3
	Earth Science	2
	Education in New Literacies	3
	ESL	28
	German	1
	History	6
	Language Arts	9
	Physics	1
	Mathematics	12
	Music (Music Education Emphasis)	1
	Spanish	6
Special Education		45

Measures

The relationship between the constructs of calibration, mathematics anxiety and achievement were examined using the data collected through self-efficacy surveys (i.e., survey for prediction), self-evaluation surveys (i.e., survey for postdiction), mathematics anxiety surveys, graded exams and final course grades. The following sections describe each of the surveys, how the surveys scores were utilized, and the reliability of each survey.

Mathematics anxiety. A ten-item survey (Appendix I) was developed by Van Gundy et al. (2006) by modifying one of Fennema and Sherman's (1976) nine Mathematics Attitudes Scales. Van Gundy et al.'s anxiety survey focused on statistics anxiety, which was changed to focus on mathematics anxiety in this study by adjusting the wording in the survey items to mention mathematics anxiety. As a result, the ten items measured anxiety related to mathematics, working on mathematics problems, and taking mathematics tests. The survey was a four-point Likert-scale survey with response choices: strongly disagree, somewhat disagree, somewhat agree and strongly agree. The survey score ranged from 10 to 40 with a higher score indicating higher math anxiety. For the present study, the reliability of the survey was determined using Cronbach's alpha and test-retest reliability coefficient. The Cronbach's alphas were .93 and .95 when the surveys were administered the first and last weeks of the semester, respectively, while the test-retest reliability coefficient was .81. These values are acceptable by Gall et al.'s (2007) cut off of .70.

Mathematics achievement on exams. The exams administered in the first course were created by the coordinator in conjunction with each of the instructors. For each administration of an exam, the same topics were covered by all the instructors, but some of the numbers and/or scenarios (contexts) of the exam problems were altered by the instructors with approval from the coordinator. The exams focused on mathematical content that students would need to know for their teaching careers. Consequently, each test had one or two problems that not only examined mathematical content, but were teaching scenarios problems designed to have students discuss mathematical reasoning of a hypothetical student. Most of the exam questions were open-ended (i.e., not multiple choice) with only a couple of matching problems (i.e., match the given problem to an appropriate mathematical expression that would help to solve the problem).

The exams for the third course were not coordinated between the two instructors. This caused the exams to be given at different times and the content on the exams were different as a result, except for the final exam as the two instructors covered all the same material and the final exam was cumulative. Similar to the exams from the first course, these exams focused on mathematical content that students would need to know for their teaching careers and contained mostly open-ended questions. The internal consistencies for the exams for both classes were reasonable with Cronbach's alphas greater than .60 (Gall et al., 2007).

Self-efficacy and self-evaluation. Self-efficacy and self-evaluation surveys were developed from the instructor-made exams (see Appendix J and Appendix K for example surveys). The self-efficacy surveys allowed students to estimate how well they anticipated doing on the exams, while the self-evaluation surveys allowed students to estimate how well they think they did on the exams. The instructors provided the researcher with a copy of the exam that included how much each problem was worth.

Then the researcher added a highlighted line under each problem that said, "I will receive ___ points on this problem" which the student completed. Also, at the end of the survey, the students were notified of how many points the test was worth and asked a similar prompt to the problem prompt. Any extra space was removed so that students would not attempt to do the problem on the survey, and a cover page with instructions was provided. Both surveys had these items; however, the instructions for the self-efficacy and self-evaluation surveys differed due to when the surveys were given to the students. The self-efficacy surveys were given to the students right before the exam, while the self-evaluations surveys were given the class after the exam, but before the instructors went over exam questions with the students. The Cronbach's alphas were reasonable with values greater than .70 for the self-efficacy and self-evaluations surveys for the exams (Gall et al., 2007).

Procedure

On the first day of class, students were asked to participate in the study. Those who agreed to participate signed the consent form and also filled out the mathematics anxiety survey. Also, the participants completed the mathematics anxiety survey the week before the final exam. Immediately before and the day after each exam, students were given the self-efficacy and self-evaluations surveys, respectively. They were allowed around seven minutes to complete the forms each time. As each student handed in a self-efficacy survey, the exam was given to the student to allow the student to take the remaining time to complete the exam. The next class day the self-evaluation surveys were collected at the beginning or end of class depending on each instructor's preference, but before the exams were discussed and given back to the students. Also, the copies of the graded exams were obtained from the instructors before they were given back to the students. After the semester ended, participants' final grades were also obtained by requesting the final grades of all students from instructors, and deleting non-participants from the data. Thirty-five (23.81%) students provided complete data for the study.

Data Analysis

Calculating calibration accuracy and bias. The self-efficacy and self-evaluation surveys were one way of measuring calibration prediction and postdiction judgments. The self-efficacy item scores, except the last item that asked students to indicate how many points they would get on the entire exam, were used to calculate the local prediction calibration, while the self-evaluation item scores were used to calculate the local postdiction calibration. The last item on the self-efficacy and self-evaluation surveys were used to calculate the global prediction and postdiction calibration, respectively.

Methods similar to Hacker et al.'s (2008b) methods for calculating calibration accuracy and bias were utilized in this study. One main difference in methods for calculating calibration accuracy lay in the fact that the self-efficacy scores were point values, instead of a confident judgment using a 10-point or 100-point scale, or continuous confidence line. The other change in methods was that the calibration scores were standardized by dividing the total number of points by what each exam was worth.

To calculate local prediction calibration accuracy, the sum of the absolute difference between the judged performance before the test and the actual performance for each problem was divided by the total number of points each exam was worth. In other words, the formula for local prediction calibration accuracy scores was as follows:

$$\mathit{Local\ Prediction\ Calibration\ Accuracy}$$
$$= \frac{\sum_{i=1}^{n} |self - efficacy\ score\ on\ question\ i - actual\ score\ on\ question\ i|}{total\ points\ for\ the\ test}$$

where *n* represents the total number of problems on the exam. Using this calculation, local prediction calibration accuracy ranged from zero to one such that zero represents a person with perfect accuracy and one represents a person with a complete lack of accuracy. Local prediction calibration bias was calculated by dropping the absolute value in the previous calculation. The bias ranges from negative one to positive one where negative one represents a student with complete underconfidence, positive one represents complete overconfidence, and zero represents no under- nor overconfidence in a person's ability on a test.

To calculate global prediction calibration accuracy, the absolute value of the difference between the judged overall performance before the test and the actual overall performance was divided by the total number of points each exam was worth. In other words, the formula for global prediction calibration accuracy scores was as follows:

$$\mathit{Global\ Calibration\ Accuracy\ Score}$$
$$= \frac{|estimated\ prediction\ score\ on\ the\ exam - actual\ score\ on\ the\ exam|}{total\ points\ for\ the\ exam}.$$

Global prediction calibration bias was calculated by dropping the absolute value in the previous calculation. With these calculations, global prediction calibration accuracy and bias values provided the same indications as local prediction calibration accuracy and bias. Local and global postdiction calibration accuracy and bias were calculated the same way as their prediction calibration counterparts, except for self-efficacy scores being replaced with self-evaluation scores.

Statistical analysis. Due to the nature of the data and the research questions, ANOVAs and multiple linear regression were utilized for the analysis. The ANOVAs helped to answer the first three research questions. Due to small number of complete data (35 participants) for the semester, multiple ANOVAs were utilized for the first three research questions. Two-way ANOVAs were conducted for the first two research questions, and mixed ANOVAs for the third question. Additionally, a correlational analysis was used before the linear regression as the purpose of this study is to examine the relationship between calibration, mathematics anxiety and achievement, and to check the assumptions for multiple linear regression.

Results

This section summarizes the results of the statistical analyses conducted to answer the research question. First, the descriptive statistics results that are related to the research questions are discussed. Then the correlational analysis between the key variables in analysis are examined. Lastly, the ANOVAs and multiple linear regression are discussed.

Descriptive Statistics

Table 3.3 includes the descriptive statistics of the calibration accuracy, mathematics anxiety and exam performance for all the pre-service elementary teachers that participated in the study. As summarized in Table 3.3, the local prediction and postdiction calibration accuracy scores of the participating pre-service elementary teachers remained somewhat stable throughout the semester, while the global prediction and postdiction calibration accuracy scores slightly decreased. Teachers Y and Z, who taught the third course for pre-service elementary teachers, had lower local calibration scores than the other teachers for the local scores. The local and global prediction and postdiction calibration bias scores for all the instructors tended around the score of zero throughout the semester, which indicated that students were generally not too over- or underconfident in their ability. Overall, these patterns show that calibration tends to remain stable throughout these mathematics courses. The only exception to this was global calibration accuracy, which indicated that students were becoming slightly more accurate in their calibration over the semester. Also, teachers may influence students' calibration as students taught by different instructors had slightly different changes in calibration throughout the semester. In particular, students in Teacher X's class tended to differ from other students in that they tended to be the least calibrated when compared to the other participants.

Table 3.3

Descriptive Summary of Calibration, Mathematics Anxiety and Exam Performance

Construct	Time	Teacher	*n*	*M*	*SE*
Local Prediction Calibration Accuracy	First Exam	V	14	.21	.04
		W	17	.22	.02
		X	20	.24	.03
		Y	32	.18	.02
		Z	34	.14	.02
		Total	117	.19	.01
	Second Exam	V	14	.25	.04
		W	14	.21	.02
		X	22	.22	.02
		Y	26	.15	.02
		Z	36	.13	.01
		Total	112	.18	.01
	Final Exam	V	14	.23	.03
		W	14	.19	.01
		X	20	.23	.02
		Y	32	.17	.02
		Z	38	.20	.02
		Total	118	.20	.01
Local Prediction Calibration Bias	First Exam	V	14	-.02	.05
		W	17	.04	.03
		X	20	.09	.03
		Y	32	-.05	.02
		Z	34	-.05	.02
		Total	117	.00	.01
	Second Exam	V	14	.03	.05
		W	14	.00	.04
		X	22	.06	.03
		Y	26	-.06	.02
		Z	36	-.08	.01
		Total	112	-.02	.01
	Final Exam	V	14	.06	.04
		W	14	.02	.03
		X	20	.08	.04
		Y	32	.00	.02
		Z	38	-.05	.02

Table 3.3, continued

Construct	Time	Teacher	*n*	*M*	*SE*
		Total	118	.01	.01
Local Postdiction Calibration Accuracy	First Exam	V	9	.17	.02
		W	14	.21	.02
		X	19	.23	.03
		Y	4	.14	.04
		Z	25	.11	.01
		Total	71	.17	.01
	Second Exam	V	10	.21	.04
		W	12	.19	.02
		X	22	.22	.01
		Y	19	.14	.02
		Z	27	.10	.01
		Total	90	.16	.01
	Final Exam	V	14	.21	.03
		W	13	.20	.02
		X	20	.19	.02
		Y	31	.13	.01
		Z	35	.15	.01
		Total	113	.16	.01
Local Postdiction Calibration Bias	First Exam	V	9	.01	.04
		W	14	.00	.03
		X	19	.08	.04
		Y	4	.01	.08
		Z	25	-.01	.02
		Total	71	.02	.02
	Second Exam	V	10	.06	.05
		W	12	-.04	.04
		X	22	.04	.03
		Y	19	-.03	.02
		Z	27	-.06	.01
		Total	90	-.01	.01
	Final Exam	V	14	.08	.04
		W	13	.02	.03
		X	20	.09	.03
		Y	31	.03	.02
		Z	35	-.04	.01
		Total	113	.02	.01

Table 3.3, continued

Construct	Time	Teacher	*n*	*M*	*SE*
Global Prediction Calibration Accuracy	First Exam	V	14	.15	.03
		W	17	.12	.02
		X	21	.17	.05
		Y	11	.08	.02
		Z	39	.12	.02
		Total	102	.13	.01
	Second Exam	V	14	.15	.04
		W	14	.11	.02
		X	22	.13	.02
		Y	34	.08	.01
		Z	38	.09	.01
		Total	122	.10	.01
	Final Exam	V	13	.12	.03
		W	13	.08	.01
		X	21	.10	.02
		Y	31	.07	.01
		Z	39	.08	.01
		Total	117	.08	.01
Global Prediction Calibration Bias	First Exam	V	14	-.01	.05
		W	17	.03	.04
		X	21	.12	.06
		Y	11	-.01	.03
		Z	39	-.02	.03
		Total	102	.02	.02
	Second Exam	V	14	.05	.06
		W	14	-.03	.04
		X	22	.02	.03
		Y	34	-.05	.02
		Z	38	-.09	.01
		Total	122	-.04	.01
	Final Exam	V	13	.02	.05
		W	13	.02	.03
		X	21	.04	.03
		Y	31	-.01	.02
		Z	39	-.04	.01
		Total	117	.00	.01

Table 3.3, continued

Construct	Time	Teacher	*n*	*M*	*SE*
Global Postdiction Calibration Accuracy	First Exam	V	9	.12	.04
		W	13	.11	.03
		X	22	.20	.05
		Y	3	.06	.02
		Z	29	.08	.01
		Total	76	.12	.02
	Second Exam	V	9	.09	.05
		W	12	.10	.01
		X	22	.12	.02
		Y	21	.10	.04
		Z	28	.06	.01
		Total	92	.09	.01
	Final Exam	V	13	.11	.03
		W	14	.08	.02
		X	22	.09	.02
		Y	29	.05	.01
		Z	36	.06	.01
		Total	114	.07	.01
Global Postdiction Calibration Bias	First Exam	V	9	.03	.06
		W	13	-.01	.04
		X	22	.08	.07
		Y	3	-.03	.04
		Z	29	-.01	.02
		Total	76	.02	.02
	Second Exam	V	9	.05	.05
		W	12	-.03	.03
		X	22	.01	.03
		Y	21	-.09	.04
		Z	28	-.06	.01
		Total	92	-.04	.01
	Final Exam	V	13	.06	.04
		W	14	.02	.03
		X	22	.05	.02
		Y	29	.02	.01
		Z	36	-.04	.01
		Total	114	.01	.01

Table 3.3, continued

Construct	Time	Teacher	*n*	*M*	*SE*
Exam Performance	First				
	Exam	V	17	79.18	3.81
		W	18	77.28	3.48
		X	21	75.71	3.69
		Y	42	87.40	1.44
		Z	38	87.00	1.27
		Total	136	83.12	1.11
	Second				
	Exam	V	17	73.76	4.40
		W	17	79.24	3.38
		X	22	76.32	2.86
		Y	41	88.91	1.37
		Z	40	94.93	.83
		Total	137	85.56	1.16
	Final				
	Exam	V	15	72.53	4.70
		W	17	76.41	3.82
		X	22	76.00	3.04
		Y	39	85.49	1.61
		Z	40	88.83	1.16
		Total	133	81.70	1.14
Mathematics Anxiety	First				
	Week	V	18	28.75	1.52
		W	20	26.80	1.36
		X	21	27.24	1.22
		Y	42	27.64	.89
		Z	41	26.06	.90
		Total	142	27.15	.49
	15^{th} Week				
		V	8	26.63	3.17
		W	10	30.80	1.80
		X	20	27.35	1.68
		Y	35	26.20	1.22
		Z	29	24.95	1.09
		Total	102	26.55	.69

The differences between local prediction and postdiction calibration accuracy scores in Table 3.3 indicate that students were more accurate with their local postdiction calibration than their local prediction calibration throughout the semester, while the differences in bias scores indicate that students tended to be slightly more confident after the exam. A similar pattern appears when examining the differences between the global prediction and postdiction calibration accuracy and bias scores, except the differences between the global prediction and postdiction scores were not as large as the difference between the local scores. The patterns related to postdiction and prediction calibration could be due to students discussing their exam answers with each other after the exam up to the next class day. Other researchers (e.g. Gutierrez & Price, 2017) have found a similar relationship between prediction and postdiction calibration.

Overall, the pre-service elementary teachers' mathematics anxiety decreased between the beginning and end of the semester; however, this could be due to the decrease in mathematics anxiety in the students taking the third mathematics content course. Students of Teachers V, W and X tended to have their mathematics anxiety increase, which were in the first mathematics content courses. Meanwhile, the exam performance of students tended to increase from the first to second exam, but then decreased from the second to third, final, exam. The differences between the second and final exam scores may be due to the final exams being cumulative. The only instructor that had students not following this pattern was Teacher V, which had exam performance decreasing throughout the semester.

Correlational Analyses

Table 3.4 presents the zero-order correlations for local and global prediction calibration accuracy and bias, mathematics anxiety and exam scores at the end of the semester for all pre-service elementary teachers. The correlation between local and global prediction calibration accuracy, and the correlation between local and global prediction calibration bias were significant in a positive moderate and strong levels, respectively. Local prediction calibration accuracy was positively correlated to mathematics anxiety at a significantly moderate level. Also, the correlations between the exam scores and the other five variables were significant. Final exam scores were negatively correlated with calibration and mathematics anxiety at a moderate to strong level. The correlations between accuracy and bias were not examined as the relationship between the two are not linear due to how the scores for both constructs are calculated. Given the correlational relationship between final exam and the other variables, these relationships are examined more closely in the multiple regression analysis.

Table 3.4

Correlations of the End-of-the-Semester Prediction Calibration, Mathematics Anxiety and Exam

Measures	LCB	GCA	GCB	MA	Exam Score
Local Calibration Accuracy (LCA)	-	.62*	-	.43*	-.72*
Local Calibration Bias (LCB)	-	-	.88*	.19	-.58*
Global Calibration Accuracy (GCA)		-	-	.10	-.39*
Global Calibration Bias (GCB)			-	.19	-.51*
Math Anxiety (MA)				-	-.54*

*$p < .001$

Analysis of Variance

To further investigate the relationship between calibration, mathematics anxiety and achievement, the researcher ran several ANOVAs. Due to the small amount of complete data collected throughout the semester, simpler ANOVAs models were chosen for analysis instead of more complex ANOVAs and MANOVAs to ensure that group sizes were adequate, and assumptions were satisfied. Additionally, the Greenhouse-Geisser correction was used for the within-subject effect in the mixed ANOVA analyses due to the violation of the sphericity assumption that the variances of the differences between all possible pairs of within-subject conditions are equal. To examine the relationship between calibration and mathematics anxiety, four two-way ANOVAs were utilized. Each two-way ANOVA was conducted to examine the effect of students' average calibration bias (underconfident, overconfident) on their change in mathematics anxiety accounting for their instructor (Teacher V, Teacher W, Teacher X, Teacher Y, Teacher Z). The students' average calibration biases were obtained from their local and global prediction and postdiction calibration bias by finding the average of each bias measurement over the three exams and then labeling each score above zero as overconfident and each score below zero as underconfident. No participant had a score of exactly zero. The two-way ANOVA with the average global prediction calibration bias was the only one to have a significant between-subject effect. In particular, the main effect of average global prediction calibration bias was statistically significant, $F(1, 60) = 4.77$, $p = .03$, while the main effect of teacher was not significant, $F(4, 60) = 1.25$, $p = .30$. This indicates that underconfident students' mean change in mathematics anxiety (M = -1.31, SD = 4.78) was significantly different than the overconfident students' mean change (M = 1.34, SD = 6.05).

The average global postdiction calibration bias ANOVA did not have a significant interact effect, but also had non-significant effects of average bias ($F(1, 44) = 1.13$, $p = .29$) and teacher ($F(3, 44) = 1.24$, $p = .31$). Similarly, the average local prediction calibration bias ANOVA had non-significant effects of average bias ($F(1, 65) = 1.91$, $p =$

.17) and teacher (F(4, 65) = 1.21, p = .32). The average local postdiction calibration bias ANOVA had non-significant effects of average bias (F(1, 37) = 3.00, p = .09), and teacher (F(4, 37) = 1.33, p = .28). Even though these ANOVAs were not significant, the underconfident students' mean change in mathematics anxiety for average global postdiction calibration bias (M = -.77, SD = 4.50), average local prediction calibration bias (M = -.95, SD = 3.67), and average local postdiction calibration bias (M = -1.02, SD = 4.49) was different from the overconfident students' mean change in mathematics anxiety for average global postdiction calibration bias (M = .83, SD = 3.94), average local prediction calibration bias (M = .50, SD = 3.83), and average local postdiction calibration bias (M = 1.18, SD = 4.10).

To examine the relationship between mathematics anxiety and achievement, a two-way ANOVA was conducted. This examined the change in mathematics anxiety between final grade levels (A, B, C, D/F) accounting for their instructor (Teacher V, Teacher W, Teacher X, Teacher Y, Teacher Z). The main effect of final grade was significant, F(3, 93) = 3.00, p = .04, while the main effect of teacher was not, F(4, 93) = .56, p = .69. Posthoc comparisons using Tukey HSD test at $\alpha = .05$ indicated that mean change in mathematics anxiety for A students (M = -1.23, SD = 3.35) were significantly different from the mean change for C students (M = 2.42, SD = 4.08). Even though B and D/F students did not significantly differ from the other grade level students, B students had a decrease in mathematics anxiety (M = -.30, SD = 4.12), while D/F had an increase in mathematics anxiety (M = 3.40, SD = 5.03).

To examine the relationship between calibration and mathematics achievement, eight mixed ANOVAs were conducted. These models investigated the effect of final grade performance on the change of calibration over time accounting for instructor. The within-subject factor was the time points of the three exams, while the between-subject factors were final grade (A, B, C/D/F) and teacher (Teacher V, Teacher W, Teacher X, Teacher Y, Teacher Z). The A students had a final grade of 89.5% or higher, B students had a final grade from 79.5% up to 89.5%, C students had grades ranging from 69.5% to 79.5%, D students had grades between 59.5% and 69.5%, and F students had grades lower than 59.5%. The dependent variables for the eight mixed ANOVAs were the eight calibration measures, local and global prediction and postdiction calibration accuracy and bias. Only the mixed ANOVA with global postdiction calibration accuracy did not have any significant effects.

For the local prediction calibration accuracy ANOVA, the main effect of time (i.e., the exam 1, exam 2, final exam) on local prediction calibration accuracy was significant, $F(1.74, 128.84) = 4.42$, $p = .02$. Also, the only interaction effect that was significant was the one between final grade and teacher, $F(6, 74) = 2.43$, $p = .03$. Post hoc comparisons of time using Tukey HSD test showed that students were more accurate in their local prediction calibration on the second exam (M = .19, SD = .12) compared to the final exam (M = .22, SD = .11) at a significantly level. Using Bonferroni correction at $\alpha = .05$, simple main effects analysis showed that students of Teacher X were significantly less calibrated compared to students of Teacher W ($p < .01$), Teacher Y ($p < .01$), and Teacher Z ($p < .01$) for C/D/F grade students, but there were no differences between teachers for A and B students.

The mixed ANOVA with local prediction calibration bias showed that the interaction effect between time (i.e., exam 1, exam 2, final exam), final course grade and teacher was significant, $F(10.25, 128.11) = 2.12$, $p = .03$. Using Bonferroni correction at $\alpha = .10$, simple main effects analysis showed that on the first exam, Teacher X's students were significantly more confident than students for Teacher Z ($p < .01$) for B students, and Teacher Y ($p < .01$) for C/D/F students, but there were no differences between teachers for A students. On the second exam, Teacher X's students were significantly more confident than students for Teacher Y ($p < .01$), and Teacher Z ($p < .01$) for B students. On the final exam, Teacher X's students were significantly more confident than students of Teacher W ($p < .01$), and Teacher Z ($p < .001$) for C/D/F students.

For the mixed ANOVA with global prediction calibration accuracy, the main effect of final course grade was significant, $F(2, 81) = 786$, $p = .001$. The main effect of time and teacher were not significant, $F(1.50, 121.61) = 1.62$, $p = .21$ and $F(3, 81) = .77$, $p = .55$, respectively. Post hoc comparisons of final course grade using Tukey HSD test showed that A students (M = .06, SD = .10) were more accurate in their global prediction calibration than B (M = .12, SD = .08) and C/D/F students (M = .15, SD = .09).

For the mixed ANOVA with global prediction calibration bias, final course grade ($F(2, 81) = 3.85$, $p = .03$) was significant, while time (i.e., exam 1, exam 2, final exam) ($F(1.45, 117.30) = 3.34$, $p > .05$), and teacher ($F(3, 81) = 1.81$, $p = .14$) were not significant. Post hoc comparisons of final course grade using Tukey HSD test showed that A students (M = -.04, SD = .13) and B students (M = -.02, SD = .12) were significantly less confident in their global prediction calibration than C/D/F students (M = .07, SD = .12).

The mixed ANOVA with local postdiction calibration accuracy showed that the interaction effect between time, final course grade and teacher was significant, $F(6.73, 65.63) = 2.91$, $p = .01$. Using Bonferroni correction at $\alpha = .10$, simple main effects analysis showed that on the first exam, Teacher X's students were significantly less accurate in their local postdiction calibration than students for Teacher V ($p < .001$), Teacher W ($p < .001$), Teacher Y ($p < .001$), and Teacher Z ($p < .01$) for C/D/F students, but there were no differences between teachers for A and B students. On the second exam, Teacher X's students were significantly less accurate in their calibration than students for Teacher Y ($p < .01$) for A students. On the final exam, there were no differences between teachers for A students. For B students, Teacher V's students were significantly less accurate than Teacher X ($p < .01$) and Teacher Y ($p < .01$). For C/D/F students, Teacher Z's students were significantly more accurate than students of Teacher V ($p < .01$), Teacher W ($p < .01$) and Teacher X ($p < .001$).

For the mixed ANOVA with local postdiction calibration bias, the interaction effect between time, final course grade and teacher was significant, $F(6.03, 58.80) = 3.49$, $p < .01$. A Bonferroni correction at $\alpha = .10$ was utilized. Simple main effects analysis showed that on the first exam, Teacher W's students were significantly less confident than students of Teacher X ($p < .01$) for C/D/F students, but there were no differences between teachers for A and B students. On the second exam, Teacher X's students were significantly more confident than students for Teacher Y ($p < .01$), and Teacher Z ($p < .01$) for B students. On the final exam, there were no significant differences in bias between the instructors for students of any grade level.

The global postdiction calibration accuracy ANOVA showed final course grade (F(2, 52) = 2.19, p = .12), time (F(1.32, 68.65) = 1.09, p = .32), and teacher (F(2, 52) = 1.71, p = .18) were not significant.

The global postdiction calibration bias ANOVA exhibited that the main effect of final course grade (F(2, 52) = 4.27, p = .02) was significant, while the main effects of time (F(1.29, 67.21) = 2.12, p = .14), and teacher (F(2, 52) = .72, p = .55) were not significant. Post hoc comparisons of final course grade using Tukey HSD test showed that A students (M = -.04, SD = .12) were more accurate in their global postdiction calibration than B (M = .03, SD = .11) and C/D/F students (M = .07, SD = .10).

Multiple Regression Analysis

Multiple linear regression was used to investigate the influence of calibration and mathematics anxiety on mathematics achievement. In particular, the influence of local and global prediction calibration, and end-of-the-semester mathematics anxiety on final exam performance accounting for instructor was examined. A step-up strategy was implemented to build the regression model. The starting model included four indicator variables to identify the five instructors, end-of-the-semester mathematics anxiety, local and global prediction calibration accuracy and bias for the final exam. Then interaction terms, starting with two-way interactions, were added one at a time and kept if the term was significant. To avoid multicollinearity between mathematics anxiety and calibration variables and their corresponding interaction terms, mathematics anxiety and calibration variables were centered.

Table 3.5 shows the parameter estimates for mathematics anxiety, calibration variables and indicator variables for the instructors along with the significant interaction terms of mathematics anxiety and Teacher X, mathematics anxiety and Teacher W, and mathematics anxiety and global prediction calibration bias. The regression model indicated the predictors explained 90.5% of the variance ($R^2 = .91$, $F(12, 74) = 58.67$, $p < .001$).

Table 3.5

Parameter Estimates for Final Multiple Linear Regression Model

Variable	Estimate	*SE*
Intercept	83.90	.79
Local Prediction Calibration Accuracy	-82.09***	6.04
Local Prediction Calibration Bias	-40.18***	6.73
Global Prediction Calibration Accuracy	-16.78*	7.49
Global Prediction Calibration Bias	-1.06	8.36
Mathematics Anxiety	-.11	.08
Teacher V	-.95	1.73
Teacher W	-4.63*	1.86
Teacher X	-2.39	1.26
Teacher Y	.374	1.09
Mathematics Anxiety X Teacher V	-.41**	.18
Mathematics Anxiety X Teacher W	-.90*	.28
Mathematics Anxiety X Global Prediction Calibration Bias	1.47*	.67

* $p < .05$, ** $p < .01$, *** $p < .001$

Given the interaction between mathematics anxiety and instructor, and mathematics anxiety and global prediction calibration bias, the interpretation of mathematics anxiety's influence on exam performance differs by Teacher V and global prediction calibration bias, while the other main effects in the model do not depend on teacher. The model indicates that as participants' local prediction calibration accuracy scores decrease by .05 (or the absolute difference between perceived and actual performance decreases by 5 points on a 100-point exam), their exam scores increases by 4.10%, while the decrease of .05 in global prediction calibration accuracy leads to an increase by .84% on exam performance. As participants' local prediction calibration bias scores decrease by .05 (or their confidence decreases by 5 points on a 100-point exam), their exam performance increases by 2.01%. A decrease of .05 for their global prediction calibration bias score leads to a .68%, 1.42%, 2.15%, and 2.94% increase in exam performance for mathematics anxiety scores of 10, 20, 30 and 40, respectively. Also, as the participants' mathematics anxiety increases by 1, their exam scores decrease by .59%, .45%, .37%, and .15%, and increase by .22% for Teacher V at global prediction calibration bias of -.05, .05, .10, .25, and .50, respectively. Meanwhile, an increase of mathematics anxiety by 1 leads to a decrease in exam performance of 1.08%, .94%, .86%, .64% and .28% for Teacher W at global prediction calibration bias of -.05, .05, .10, .25, and .50, respectively. For Teacher X, Y, and Z, an increase of mathematic anxiety by 1 leads to a decrease in exam performance of .18%, .04%, and an increase of .04%, .43% and .63% at global prediction calibration bias of -.05, .05, .10, .25, and .50, respectively.

Discussion

The purpose of this paper was to investigate the relationship between calibration, mathematics anxiety and mathematics achievement for pre-service elementary teachers.

This was accomplished by focusing on global and local calibration accuracy and bias along with mathematics anxiety, exam performance and final course grade data, and conducting aforementioned data analyses.

Research Question 1 Answer

With regards to the first research question, the results of the difference in the change of mathematics anxiety between underconfident and overconfident students accounting for instructor were expected. Over the semester, the underconfident students as determined by the average global prediction calibration bias had a significant decrease in mathematics anxiety, while the overconfident students had a significant increase in their mathematics anxiety. This pattern also held for the other bias measurements even though the differences were not significant. According to underestimation bias, underconfident students are more likely to perform better on exams than overconfident students (Pajares, 1996; Stone, 2000). This may be because underconfident students are more likely to spend more time studying the topics necessary for an upcoming exam than overconfident students are, which may include additional time studying material that they do not actually know well enough. Because prior mathematics achievement has significant impact on students' mathematics anxiety later (Frenzel, Pekrun, & Goetz, 2007; Ma & Xu, 2004; Meece et al., 1990), and underconfident students performing better than expected on previous exams, these performances on exams could have led to a decrease in mathematics anxiety. Similarly, the influence of prior mathematics achievement on mathematics anxiety and the fact that overconfident students performed worse than expected on exams (prior to the administration of the anxiety survey on the last week of classes) could have led to overconfidence students' mathematics anxiety to increase throughout the semester.

Research Question 2 Answer

The second research question pertained to the relationship between mathematics anxiety and achievement by investigating the change in mathematics anxiety based on students' final course grade levels. The A and B participants tended to reduce their mathematics anxiety throughout the semester, while the C, D and F students tended to have their mathematics anxiety grow. Accordingly, the change in mathematics anxiety across each grade-level group indicates that as mathematics achievement increases, the change in mathematics anxiety decreases. In other words, the students' end-of-the-semester mathematics anxiety compared to their initial mathematics anxiety seems to depend on their mathematics achievement in class throughout the semester. This result is consistent with results of studies by Frenzel et al. (2007), Meece et al. (1990), and Ma and Xu (2004). Alsup (2005), Johnson and vanderSandt (2011), and Tooke and Lindstrom (1998) also found that pre-service elementary teacher mathematics content courses lead to a reduction in mathematics anxiety, especially for courses designed with the methodology for teaching mathematics in mind. However, they did not examine the change in mathematics anxiety for differently achieving students. In the present study, 42.86% of the students earned A's and 34.29% earned B's, which were the groups that had a decrease in mathematics anxiety.

Research Question 3 Answer

The third research question investigated the relationship between calibration and mathematics achievement by exploring local and global prediction and postdiction calibration accuracy and bias for different achievement levels throughout the semester. The courses that the students took were coordinated. Teachers V, W and X, and Teachers Y and Z covered the same topics and activities, taught in a student-centered manner, and tested the same material. The only difference in the exams between Teachers V, W and X was the scenarios for a couple of problems were tweaked to fit the instructor, but still tested the same topics. For Teachers Y and Z, their exams were not given at the same time, except for the final exam, and did not cover the exact same material as a result; however, over the entire semester, they did cover the same mathematical topics. The results of the mixed ANOVAs indicate that the type of teacher (i.e. different teachers), content covered (i.e. different courses and different topics on each exam), and the students' level of course achievement can influence pre-service elementary teachers' calibration. In particular, instructors tend to have more influence on the lower achieving students' local calibration, especially for prediction calibration, but this sometimes depends on the course and what content is covered by the exam. Additionally, higher achieving students tend to be more globally calibrated.

As mentioned in the literature review, as students become less confident and more accurate with their calibration, their mathematics achievement increases. The results found in this study with respect to relationship between students' final course grade and calibration, except for global postdiction calibration accuracy, supports the findings in the previous studies. Additionally, this relationship can be influenced by the content on the exam as Hacker et al. (2008b) mentioned that calibration is a domain specific construct. Even though the exams covered mathematics subjects, the exams for the first course and third course covered different topics within mathematics in which students could have different calibrations. Additionally, the students in the third course had experience with the style of teaching for the pre-service elementary teacher courses, which means they are more used to the types of questions asked on the exams. These students could already be better calibrated as a result.

The different teachers have different styles of the teacher- and/or student-centered approach to teaching, of communication with the students, and of giving feedback to the students on presentations, assignments and assessments. Hacker et al. (2000), Nietfeld et al. (2006), and Labuhn et al. (2010) have found certain types of feedback causes students to have better calibration accuracy and less calibration bias, while Nietfeld et al. (2005) and Schraw et al. (1993) found that feedback does not improve calibration. Hacker et al. (2000) reported that only high achieving students became more calibrated when students received feedback over several exams. Nietfeld et al. (2006) stated that weekly practice of calibration prediction accuracy with feedback from the instructor improved calibration. Labuhn et al. (2010) showed that students who received feedback were more accurate and less biased in their calibration postdiction than those students who did not receive any feedback. Additionally, overconfident students became more accurate in their calibration; in particular, social comparison feedback led to higher calibration prediction accuracy and less bias compared to individual feedback for overconfident students. Bol et al. (2012), and Gutierrez and Price (2017) suggested that the social interactions within the group can improve students’ calibration. As the teacher determines the feedback provided to students and assists in shaping groups interactions during group work, the teacher can influence students’ calibration.

Research Question 4 Answer

The fourth research questions examined the predictive nature of calibration and mathematics anxiety on mathematics achievement by investigating the connection between prediction calibration, mathematics anxiety and exam performance on the final exam. For the constructs related to the final exam, the positive and significant correlations between local and global calibration accuracy, and local and global calibration bias indicate that these measurements are similar in nature, and the scope of their measurement is what makes the measurements different. The correlations between calibration and final exam score suggest that as students become more accurate and underconfident in their calibration, their exam scores increase. Previous calibration research has found similar results for accuracy correlations, bias correlations, and their correlations with respect to exam performance (Chen, 2003; Chen & Zimmerman, 2007; Ozsoy, 2012).

An additional potential implication of the above correlations is that as students become less math anxious, they become more accurate on their local prediction calibration and, as a result, do better on the final exam. Additionally, although not at a significant level, less mathematics anxiety can lead to lower confidence and more accurate global prediction calibration. Overall, as a student becomes less math anxious, they become more accurate in calibration, and less confident. This result fits within previous research and the metacognitive model by Van Overschelde’s (2008), and Nelson and Narens (1990, 1994). Mathematics anxiety can affect students’ metacognitive monitoring and control. For metacognitive control, mathematics anxiety can act as an internal perceived constraint, which limits what control actions a person utilizes when studying and solving problems. This could lead to students not studying suitably and/or efficiently, and to fail to solve problems they can solve. For metacognitive monitoring, mathematics anxiety can inhibit a student's mathematical problem solving and ability to calibrate by limiting the amount of information contained in working memory (Ashcraft, 2002; Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Raghubar et al., 2010). When attempting to calibrate, the amount of information stored in a student's working memory can be reduced by their mathematics anxiety level. For example, the higher anxiety level could mean students' working memory is less than the lower anxiety students' working memory. This can cause the problem in the students' working memory to not possess all the necessary information and, as a result, can cause the students to make their prediction calibration judgment within the dynamic model at the meta-level using an incomplete picture. This can lead the students to be less accurate and more confident in their calibration.

The multiple linear regression supported some of the indications from the correlations. The influence of local prediction calibration on the final exam performance matched the correlation analysis, which corresponds to the research discussed in the literature review. In other words, as students become more calibrated, their performance increases. Global calibration accuracy has similar effect, but to a smaller effect than local calibration accuracy. This supports Nietfeld et al. (2005) assertion that local accuracy has more influence on students' exam performance. Meanwhile, the influence of global calibration bias on exam performance intertwines with the influence of mathematics anxiety. The interaction between mathematics anxiety and global prediction calibration bias demonstrates as students' mathematics anxiety increases and confidence decreases for global calibration bias, their exam performance increases as a result of the interaction. The interaction between the two constructs fit within Nelson and Narens's (1990, 1994) metacognitive model through metacognitive monitoring. For metacognitive monitoring, mathematics anxiety can lower the confidence students possess and use when making decisions while studying because mathematics anxiety and confidence measurements have been found to be negatively correlated (Ashcraft, 2002; Jameson & Fusco, 2014; Legg & Locker, 2009; Malpass et al., 1999). The lower confidence may cause them to study topics more than they needs to for an exam. In particular, the additional studying on the topics that the student does not know well enough can lead to better exam performance.

Besides the interaction with global prediction calibration bias, mathematics anxiety significantly interacted with Teachers V and W. This shows that the teacher can influence the link between mathematics anxiety and exam performance for pre-service elementary teachers. The instructors for the pre-service elementary teacher courses can influence the link between mathematic anxiety and achievement through the structure and teaching methods used (e.g., Brady & Bowd, 2005; Lorenzen, 2017), creating negative experiences in mathematics classes (e.g., Bekdemir, 2010; Harper & Daane, 1998), and generating negative experiences with the students (e.g., Brady & Bowd, 2005; Harper & Daane, 1998). Overall, the terms with mathematics anxiety indicate that as underconfident students become more math anxious, their exam performance decreases; meanwhile, overconfident students may have a different decrease or increase in their exam performance depending on their instructor and how overconfident the students are. Even though mathematics anxiety can inhibit pre-service elementary teachers' metacognitive monitoring and control during studying and test taking, and mathematics anxiety tends to be higher in pre-service elementary teachers, the impact seems to be limited compared to other constructs' influence on mathematics exam performance. However, mathematics anxiety is still important to performance due to the influence mathematics anxiety has on other constructs that are also related to performance (Chang & Beilock, 2016). The limited impact of mathematics anxiety in this study may be due to measuring the end-of-the-semester mathematics anxiety a class or two before the final exam, while other researchers administered the math anxiety surveys at the time of their other measurements.

Limitations

There were several limitations of this study, which involved when the end-of-the semester mathematics anxiety was measured, wording of self-efficacy and self-evaluation surveys, and a couple of problems with collecting self-evaluation surveys. As mentioned previously, the end-of-the-semester mathematics anxiety was measured one or two class days before the final exam. As a result, the mathematics anxiety in the multiple linear regression may not represent the mathematics anxiety the students had when taking the test. One reason for this is due to several students mentioning that they had started studying for the test the day of or the day before the exam. Those that had not studied before taking the mathematics anxiety survey may not have known what they knew or did not know of the material for the test. By the time they took the exam, their mathematics anxiety could have changed depending on how well they learned the material. Hence, the relationship between mathematics anxiety and other constructs in this study may be smaller than they would have been otherwise. The main reason for not measuring mathematics anxiety right before the exam was due to concern from the mathematics coordinators and instructors of the pre-service elementary teacher courses. They felt that measuring mathematics anxiety right before the exams would cause students to more actively think about their mathematics anxiety when taking the exams and, as a result, lead them to perform worse on the exams.

An issue related to the format of the self-efficacy and self-evaluation surveys is how confidence is measured. Instead of utilizing a confident judgment using a 10-point or 100-point scale, or confidence line as suggested by Hacker et al. (2008b), students used point values to determine their confidence due to the nature of the exam problems and to have students account for how they believed their teacher grade those problems. Most exam questions were open-ended with a few being multiple choice or matching problems. Open-ended questions make it hard to determine what a certain level of confidence means in terms of point values. Thus, students were asked to take an additional step, and use their confidence and knowledge of their instructor to determine how many points they would get per problem or part of a problem as this is more aligned with their current thoughts when it comes to success on an exam. Even though this does not follow the standard convention described by Hacker et al. (2008b) for calculating calibration accuracy and bias, Alexander (2013) mentioned that there is no standard way to collect calibration judgments and to calculate calibration. Also, Bol et al. (2012) used point values when determining global calibration accuracy. Therefore, the current findings related to calibration may not correspond to other calibration prediction surveys, nor to other calibration accuracy and bias findings.

The issues related to collecting self-evaluation surveys are due to an error by an instructor, a couple of class's situation after the second exam, and the collection of the surveys for the final exam. One of the instructors for the third mathematics content course of the three-course sequence accidently put up the exam scores for the first exam on Blackboard's grading system for students to see before the self-evaluation surveys were given. As a result, students did not need to estimate their overall performance on the exam, while at the same time, they estimated their item-by-item performance (local calibration) in such a way that their item estimations summed to their exam score. In order to not bias the data, the postdiction calibration scores calculated from these self-evaluation surveys were not used in the analysis. Due to the classroom situation after the second exam in one class for each course, the self-evaluation surveys were delayed by a class day. This may have caused students to not remember the problem and their work as clearly as the students who did the survey the class after the exam. Thus, these students' postdiction calibration scores may not correspond to the other students' scores. For the first two exams, the self-evaluation surveys were mainly administered the class day after the exam, but for the final exam, that was not possible. As a result, the surveys were given to students right after they finished the final exam. This could cause students to be less calibrated on the final exam. The first two exams allowed students to discuss the problems and answers with other students, and reflect on that information, while the students did not have that opportunity for the final exam.

Implications

Based on the findings and limitations of this study, there are several implications for educational practices and research. An educational implication is to advocate for metacognition training and group work in the classroom. Kruger and Dunning (1999) found that improving students' calibration ability would help them recognize the limitations of their abilities and knowledge. The benefit of improving calibration was greater for the lower achieving students as they tended to make poor decisions and did not have the metacognitive abilities to recognize it. Furthermore, Cardelle-Elawar (1995), Bol et al. (2012), Kramarski and Mevarech (2003) and Kramarski and Dudai (2009) proposed that metacognitive training, which includes the skills necessary for calibration, is beneficial to students' understanding and performance. Cardelle-Elawar (1995) examined low math achieving students in third to eighth grade by randomly assigning them to a traditional instruction or a metacognitive training instruction. The students who received metacognitive training answered questions throughout the problem-solving process that related to functions of metacognition such as whether they understood what the problem was asking and what operations that were needed to solve a problem did the student have difficulty completing. Similarly, on the review day before an exam, Bol et al. (2012) utilized metacognitive guidelines that asked high school students to address how well they are understanding the concepts being learned, which was utilized after students were given some time to reflect over their understanding of biology content. Kramarski and Mevarech (2003) investigated whether the IMPROVE method, which focused on improving students' metacognitive abilities, helped eighth and ninth graders with their performance. Kramarski and Dudai (2009) investigated how metacognitive guidance, which was operationalized as self-questioning strategies to prompt self-regulation during problem-solving, influenced ninth graders' mathematics performance. All four found that those who received metacognitive training significantly improve their math performance compared to the traditionally taught students. Additionally, Bol et al. (2012), Kramarski and Mevarech (2003) and Kramarski and Dudai (2009) found that working in groups improved student achievement, while metacognitive training combined with working in groups provided the best environment for improving student performance. Bol et al. (2012) also found that students who utilized their guidelines in groups displayed the greatest global calibration prediction and postdiction accuracy.

Another method to improve students' calibration may be to provide students with an opportunity to practice calibration through the course along with feedback that prompts them to self-reflect on their knowledge. Nietfeld et al. (2006) found weekly monitoring practice on quizzes with feedback caused students to become better calibrated in a psychology course. However, some researchers (e.g., Schraw et al., 1993) suggest that feedback does not help student calibrate. Feedback may only be useful when it allows some self-reflection to take place because self-reflection can help students improve their calibration and performance in mathematics (DiGiacomo & Chen, 2016; Ramdass & Zimmerman, 2008; Zimmerman et al., 2011). Also, the nature of the feedback is important as Labuhn et al. (2010) and Hacker et al. (2000) suggested that certain types of feedback are more useful for improving calibration. Thus, researchers should investigate whether calibration practice in the mathematics classroom would improve students' calibration, and what types of teacher feedback and reflection prompts would help improve calibration.

Due to the lack of extensive research, the suggestions of Chang and Beilock (2016) and Herts and Beilock (2017) on further investigation of factors that may affect the link between mathematics anxiety and achievement, when mathematics anxiety was measured for the final exam, and the interaction term between mathematics anxiety and global prediction calibration bias in the multiple linear regression equation, future plans should be to conduct further research on the connection between mathematics anxiety and calibration, and their collective influence on mathematics achievement. Researchers could investigate whether mathematics anxiety moderates the relationship between calibration and mathematics performance, or calibration moderates the relationship between mathematics anxiety and performance. Based on the findings of the multiple linear regression and Legg and Locker's (2009) findings, the latter seems more likely. Another research investigation could examine how calibration mediates the link between mathematics anxiety and performance through the examination of working memory and the limitations caused by the anxiety along with how the limited working memory interacts with Nelson and Narens's (1990, 1994) metacognitive model.

CHAPTER IV

PRE-SERVICE ELEMENTARY TEACHERS' MINDSET AND ITS RELATIONSHIP WITH CALIBRATION, MATHEMATICS ANXIETY AND ACHIEVEMENT

Introduction

In the last couple of decades, mindset has become an important topic within mathematics education (Boaler, 2016; Dweck, 2006). Dweck (2006) defines mindset as the view people have about the malleability of their intelligence, stating that people who believe their intelligence can develop have a growth mindset, and ones who believe their intelligence is fixed have a fixed one. Dweck (2008) mentioned that research has viewed mindset as both a dichotomy, a person is either fixed or growth mindset, and a continuum, a person's belief can be placed somewhere in between fixed and growth mindset. Dweck's earlier studies have shown that around 40% of students were observed to have growth mindset, 40% a fixed mindset, and the rest (20%) demonstrated mixed profiles (Dweck, 2008).

Overall, people's differing mindsets have powerful and long-lasting effects on their view of success as well as their performance. When students, for example, were introduced methods to make change in their beliefs from fixed to growth, they immediately started to perform better in school (Dweck, 2006). Aronson et al. (2002) examined the influence of a growth mindset intervention on college students through a comparison of an intervention group and a control group. They found that the growth mindset intervention group had a gain in achievement especially African American participants, while the control group did not. The difference in achievement between Caucasians and African American students vanished for the treatment group, while the African Americans students also displayed more enjoyment and value of their courses. Some researchers (e.g., Blackwell et al., 2007; McCutchen et al., 2016) also found that a growth mindset promotes mathematics achievement. Similar to Aronson et al.'s (2002) findings, Blackwell et al. (2007) found that growth mindset led to better mathematical performance longitudinally than fixed mindset.

In her 2015 commentary, Dweck warns about the misuse of growth mindset ideas; in particular, stating that growth mindset is not just about effort. While effort is a key part of improving student learning to enhance persistence, she emphasizes that understanding what to do when one gets stuck (e.g., analyzing and improving problem-solving strategy) is part of facilitating growth mindset. In other words, students need to be able to use their existing knowledge to determine what strategies should they use in a situation, but more importantly, to develop new strategies if existing strategies do not help. Strategy usage and development lies within the realm of metacognition model of Nelson and Narens (1990, 1994), implying that there could be a relationship between mindset and students' metacognition. As shown in research studies, metacognitive skills have been found to affect students' mathematics achievement (Legg & Locker, 2009).

One important construct within the metacognition domain that may relate to mindset is calibration of performance. Calibration is defined as how close a person's perceived performance matches to his or her actual performance on a particular task

(Hacker et al., 2008b; Nietfeld et al., 2006). Accurate calibration allows students to know what they know and do not know, which allows them to focus their studying, while inaccurate calibration causes students to spend too much time studying material they already know or not enough time on material they do not know (Hacker et al., 2008b; Stone, 2000). However, how each student uses such knowledge to focus their studying may partially be determined by the mindset the person has. Based off Dweck's (2006) work, growth mindset students seem more likely to focus on concepts they do not know, while fixed mindset students seem less likely to focus on such concepts. As a result, growth mindset students should become better calibrated, while fixed mindset students may not, and in fact, may become less calibrated. As students' calibration influences their mathematics achievement (e.g., Chen & Zimmerman, 2007; Jacobse & Harskamp, 2012), growth mindset students may perform better in mathematics than fixed mindset students partially due to their better calibration skills. However, more research is needed to examine such relationships.

As discussed in earlier chapters, mathematics anxiety is another construct that influences mathematics achievement. Mathematics anxiety can inhibit students' learning through their working memory (e.g., Ashcraft & Kirk, 2001; Beilock & Carr, 2005). Also, researchers (e.g., Andrews & Brown, 2015; Hembree, 1990) have shown that lower mathematics anxiety leads to better mathematical performance. However, can mathematics anxiety also be used more positively to help enhance students' learning? Dweck's (2006) work on mindset seems to indicate that it is possible. Due to differing views of effort and challenge, growth mindset students seem more likely to use mathematics anxiety as a motivator to study certain concepts, while fixed mindset students seem more likely to use mathematics anxiety as an indicator to avoid such topics at least temporarily. As a result, growth mindset students may have their mathematics anxiety decrease after their studying, while fixed mindset may have their mathematics anxiety increase.

Research investigating the relationship between mindset, calibration, mathematics anxiety and achievement answers the calls by Chang and Beilock (2016), Herts and Beilock (2017), and Legg and Locker (2009). Chang and Beilock (2016) suggested that further investigations into factors that could explain the link between mathematics anxiety and achievement are needed, while Herts and Beilock (2017) expanded upon this call by mentioning that more needs to be learned about how mathematics anxiety influences the learning process as this has important broader implications for teaching mathematics. Legg and Locker (2009) also suggested that further research needs to be conducted to better understand the relationship between metacognition and mathematics anxiety. The present study aims to address these calls by examining the relationship between mindset, calibration, mathematics anxiety and achievement of pre-service elementary teachers and provide additional insights of this potential relationship.

Literature Review

In this literature review section, I first provide a description of the theoretical framework that situates the constructs and possible relationship between them. In particular, I argue that within the existing metacognition model of Nelson and Narens (1990, 1994), mindset provides a world view that may provide some explanation for students' actions during metacognitive monitoring and control. This framework section is followed by sections that summarize the relationships between mindset, calibration, mathematics anxiety and achievement from existing studies.

Theoretical Framework

Van Overschelde's (2008) metacognition model, an extension of Nelson and Narens's (1990, 1994) model, provides the theoretical grounding of this study. The model has four key pieces, the object-level, meta-level, monitoring and control. Metacognitive monitoring is the flow of information from the object-level to the meta-level that affects the dynamic model, while metacognitive control is the flow of information from the meta-level to the object-level that affects the actions occurring at the object-level. Further descriptions of the metacognition model and its constructs, and discussion of possible placement of calibration and mathematics anxiety within the model were provided in chapters 2 and 3. Mindset, a new measure included in this study, may also relate to metacognition; in particular, mindset may relate to Nelson and Narens's model by acting as a view of the world that shapes people's metacognitive monitoring and control.

Dweck (2006) describes the influence of mindset on people's lives. Mindset helps to understand people's view of success and meaning of failure and effort. For fixed mindset, success is about proving that you are smart or talented, while for growth mindset, success is about learning something new in order to develop yourself. Fixed mindset people tend to focus on feedback that tells them whether they are right or wrong, but do not account for the information that can help them learn and improve their approaches to get the right answers. On the other hand, growth mindset people focus on that information to further their learning and understanding. The view of success for the two mindsets ties very closely to the meaning of failure and effort.

If fixed mindset people fail at a particular task, they view themselves as failures and should avoid this type of task in the future to avoid not looking smart. Also, if they must put in effort to do something, they believe they do not possess the ability to do so and should not bother to try more. Growth mindset people view failure as a temporary outcome that they can rectify through effort as their effort will lead to the ability necessary to challenge their previous failure. Growth mindset leads people to embrace failure, challenges and effort, while fixed mindset causes people to avoid tasks with chances of failure, fear challenge and devalue effort. Furthermore, growth mindset people believe that learning involves reflecting and learning from their mistakes. For example, Dweck (2006) mentioned that students with growth mindset view a poor test grade as something that they need to improve by studying harder for the next exam, while those with a fixed mindset view it as a failure due to the lack of ability and are not convinced more studying would improve their ability. She discovered that the growth mindset students tend to take charge of their learning and motivation to better understand the material, and go beyond rereading the course materials for memorization that fixed mindset students tend to do. This indicates that fixed mindset may cause the utilization of inferior learning strategies, which Howard and Whitaker's (2011) findings support.

Howard and Whitaker (2011) found that unsuccessful students tended to avoid mathematics by not participating in class, sitting in places to avoid being noticed in class, not asking questions, doing only assigned homework at best, avoided studying and did not ask for help, while successful students tended to reflect on advice for what course to take, position themselves in class where they would be most successful in their learning, ask questions till they understood the material, be more proactive in their study and homework habits, and look for and use resources that would help them understand the concepts. Based on Dweck's (2006) description of fixed and growth mindset students, Howard and Whitaker's (2011) characteristics of unsuccessful participants seem to have more similarities with fixed mindset view, while the successful participants' characteristics seem to have more commonalities within growth mindset view.

Nelson and Narens (1990, 1994) places the strategies that students use for studying and learning in the meta-level of the metacognition model. In particular, metacognitive monitoring and control are key to the choice of what strategy to use when studying and how to enact the strategy. During the monitoring process, students judge how well they are doing based on the information at the object-level, while students use that judgment along with their meta-level knowledge, strategies, and goals to determine what actions to perform at the object-level during the control process. Since mindset affects students' worldview, mindset also influences the decisions and actions students take within the metacognitive model by providing different interpretations of the information used for metacognitive monitoring and control.

As mindset has influence on students' view of success, failure and effort, it plays a role in students' metacognitive functions. For example, fixed mindset students taking a test may read over a problem and judge that they are not confident in doing this problem activating certain meta-level knowledge and strategies that may lead the student to not attempt the problem because they may conclude that they may fail to solve the problem correctly. Meanwhile, growth mindset students in the same situation may use their meta-level knowledge, strategies and that judgement to determine that they need to come back to this problem later to put more effort solving it.

Mindset and Mathematics Achievement

Other researchers expanded Dweck's work to different research areas. These studies have focused on several subject areas such as English, science and computer science, but of particular interest, are mindset studies related to mathematics.

Aronson et al. (2002) and Good et al. (2003) sought to reduce stereotype threat through interventions involving mindset. Aronson et al. (2002) found that African Americans and Caucasian college students performed better in their mathematics courses when the message of growth mindset was reinforced, while Good et al. (2003) found that such a message caused seventh grade females to perform better in mathematics. Since these studies, other researchers have found similar results for mathematics achievement. Blackwell et al. (2007) also examined the role of mindset in students from seventh to ninth grades. They found students with an initial growth mindset had an increase in mathematics performance over the years, while fixed mindset students had a decrease. Also, reinforcing the growth mindset belief for students can lead to a reversal in the decline of mathematics performance. Claro et al. (2016) and McCutchen et al. (2016) found mindset to be a predictor of mathematics performance with a growth mindset leading to better achievement. Additionally, a growth mindset may mitigate the negative effects of low socioeconomic status on achievement (Claro et al., 2016). Similarly, Boaler and colleagues found that the highest-achieving students on the Program for International Student Assessment (PISA) 2012 had a growth mindset, and outranked other students by the equivalent of more than a year of mathematics (Boaler, 2016).

Additionally, Boaler (2014) found that there tends to be a high level of fixed mindset thinking among girls, which may be due to advance mathematics courses not explicitly promoting a growth mindset for females (Perez-Felkner et al., 2012). This is argued to be one reason that girls tend to avoid science, technology, mathematics and engineering subjects (Perez-Felkner et al., 2012). Leslie et al. (2015) study states that mathematics was one of the subjects that professors held the most fixed mindset beliefs about who could learn the material. This seems to be a cyclic problem, as mathematical mindset held by teachers tends to influence students' mindset and then students tend to hold similar mindset beliefs when they become teachers (Boaler, 2016; Dweck, 2006; Leslie et al., 2015). These findings indicate that a growth mindset is more conducive to success, learning and achievement in mathematics, especially for underrepresented groups, and adjusting teachers' mindset about mathematics should be a priority.

Mindset and Mathematics Anxiety

As mentioned previously, Dweck (2006) and her colleagues found that the view of mindset changes the meaning of failure and effort. Students with a fixed mindset avoid situations that they have failed before, while also not putting in effort to rectify the situation. Students with a growth mindset instead challenge their failures to improve their learning by putting in effort to shore up their misconceptions and missing knowledge. These differing points of view can lead to different meaning of mathematics anxiety.

Fixed mindset students seem more likely to use their mathematics anxiety as an indicator of a mathematical topic to avoid because the anxiety indicates they are not comfortable with the topic and might fail to understand the topic. Meanwhile, growth mindset students seem more likely to use their mathematics anxiety as an indicator of where they need to focus their effort in order to better understand the material because the challenge that comes from not being comfortable with a topic is more likely to drive them to learn the material. Fixed mindset students then are more likely to become mathematically anxious over time, while growth mindset students are more likely to become less mathematically anxious. This is supported by Johnston-Wilder et al. (2015) study in which they found that mathematical resilience leads to a decrease in mathematics anxiety, where growth mindset creates resilience in the face of setback (Dweck, 2006; Yeager & Dweck, 2012).

Mindset and Calibration

Calibration as a metacognition construct may be influenced by students' mindset. As previously mentioned fixed mindset students tend to focus on feedback that tells them whether they are right or wrong, while growth mindset students focus on any information that helps further their learning and understanding. Since calibration is the alignment between a student's perceived performance and actual performance, more information that helps students better understand what went right and wrong on the problem would allow them an opportunity to better align their perceived and actual performance. How students use this opportunity seems to depend on the students' mindset.

Fixed mindset students seem less likely to use the opportunity than growth mindset students. Freund and Kasten (2011) theorized that growth mindset leads students to reflect on their performance more deeply and critically to better evaluate their errors to improve. O'Keefe (2013) indicated that growth mindset students engage in self-assessment and self-evaluation methods that lead to actions to improve their understanding, while fixed mindset students utilize self-assessment and self-evaluation methods that protect and maintain their self-image as capable individuals. This indicates that growth mindset students are more likely to become more calibrated, while fixed mindset students are more likely to become less calibrated. Dweck (2006) mentioned a study that supports this connection between mindset and calibration as she and her colleagues "found that people greatly misestimate their performance and their ability. *But it was those with the fixed mindset who accounted for almost all the inaccuracy* [author's emphasis]. The people with growth mindset were amazingly accurate" (p. 11).

Calibration and Mathematics Achievement

Calibration has become an increasingly important construct for learning of mathematics due to its relationship with mathematics achievement. The summary of existing studies was provided in Chapters II and III. Briefly, some researchers (e.g., Chen & Zimmerman, 2007; Garcia et al., 2016) have found the calibration and mathematics achievement to be significantly correlated; in particular, local prediction and postdiction calibration accuracy positively correlated with performance, while their biases negatively correlated with performance. Other researchers (e.g., Chen, 2003; Freeman et al., 2017) have found that calibration influences mathematics achievement. These studies generally indicated that better calibrated students have better performance.

Mathematics Anxiety and Achievement

The relationship between mathematics anxiety and achievement is discussed in earlier chapters (see Chapters II and III). Briefly, studies found that mathematics anxiety has an influence on mathematics learning. For example, research has shown mathematics anxiety to negatively influence mathematics performance (e.g., Andrews & Brown, 2015; Cargnelutti et al., 2017), while also providing some indications that there is a cyclic relationship between mathematics anxiety and achievement (Gunderson, Park, Maloney, Beilock, & Levine, 2018). For pre-service teachers, their mathematics anxiety not only has negative influence on themselves, but also their students. Cook (2017), and Subia, Salangsang and Medrano (2018) indicated that mathematics anxiety negatively influences their mathematics teacher self-efficacy, while Beilock et al. (2010) indicated that their future students' mathematical attitudes and ability would be hindered as a result of the pre-service teachers' mathematics anxiety.

Research Purpose and Questions

The aim of this study is to investigate how mindset relates to calibration, mathematics anxiety, mathematics achievement and their relationships with each other in pre-service elementary teacher population. This investigation will contribute to our understanding as such a relationship has not been examined empirically. Theoretically, mindset could play a role in developing students' calibration. For example, when students prepare for a test, they will consciously or unconsciously make judgements about what they know and what they do not know well enough. Using that information, growth mindset students would focus on what they have missed on previous assignments, exams and in class materials to improve their understanding. This does not mean that growth mindset students will not study the content they think they know; they may structure their preparation time accordingly. Meanwhile, fixed mindset students might tend towards focusing on the content on they already know well enough to show that they can be successful. Similar to growth mindset students, fixed mindset students may spend time with the content they judge as not knowing, but may use any failure with such content to avoid further failure. As a result, growth mindsets will have a better idea of the alignment between their actual and perceived ability, while fixed mindsets will only have a better idea of such alignment for the material they believe they know. This means that growth mindset students are more likely to better calibrated than fixed mindset students. Additionally, mindset seems to be a determiner on whether mathematics anxiety, as a perceived constraint, will be a motivator or a demotivator for students. Together with the reasons for the research conducted in Chapters II and III, additional studies are needed to improve our understanding.

Following the suggestions from Chang and Beilock (2016), Herts and Beilock (2017), and Legg and Locker (2009) about investigating constructs that may mediating the relationship between mathematics anxiety and achievement, and metacognition and mathematics achievement, this study examines the relationship between pre-service elementary teachers' mathematical mindset, calibration, mathematics anxiety and achievement in two content courses by addressing the following research questions:

Q1 Is there a statistically significant difference in calibration over time for pre-service elementary teachers who demonstrate a fixed and those who demonstrate a growth mindset throughout the semester accounting for instructor and semester?

Q2 Is there a statistically significant difference in mindset between low, moderate and high math anxious pre-service elementary teachers at the beginning and end of the semester accounting for instructor and semester?

Q3 Is there a statistically significant difference in the change in mindset for students of different achievement levels accounting for instructor and semester?

Q4 Does mindset, calibration and mathematics anxiety predict mathematics exam performance in pre-service elementary teachers accounting for semester and instructor?

Method

Sample

During the spring and fall semesters of 2017, 321 undergraduate students (142 spring, 179 fall) enrolled in the first and third mathematics content courses for pre-service elementary teachers in a required three-course sequence agreed to participate in the study. Each semester was 15-week long. The courses were taught in the mathematics department at four-year doctoral granting institution in the Rocky Mountain region. Table 4.1 summarizes the number of freshmen, sophomores, juniors and seniors enrolled in each of the courses that agreed to participate. Most of the freshmen were in the first course, while most of the sophomores, juniors and seniors were in the third course. This was typical as the elementary education students at this university are encouraged to take their mathematics courses early in their degree program. Most of the participants were female (90.03%) and white (70.09%), which was typical for these courses at this university.

Table 4.1

Grade Level by Course

Grade Level	First Course	Third Course
Freshman	84	8
Sophomore	26	77
Junior	16	72
Seniors	1	25
Unknown	9	3

The first course focused on the real number system and arithmetic operations through examining the structure and subsets of real numbers using patterns, relationships, and properties, while the third course focused on spatial reasoning in geometry and measurement through examination of two- and three-dimension shapes, and their properties, measurements, constructions and transformations. The five instructors for the courses were the same for the spring and fall semester. Teacher V, W and X taught one section of the first course each semester. Teacher Y and Z taught two sections of the third course during the spring semester, while Teacher Y taught three sections and Teacher Z taught one section during the fall semester. For both courses, students met twice a week for 75 minutes and mostly worked in groups. Even though the courses are primarily for elementary education students, students majoring in special education who focus on K-3 or K-12 education were required to take the first course along with early childhood education majors who focus on K-3 education. Additionally, a few students from other majors were enrolled in the courses, but were not included in the study.

Most of the participants (73.52%) were elementary education majors with most being on either the cultural and linguistic diversity track (33.33%) or the special education track (19.94%). There were 45 (14.02%) participants that majored in special education, and 53 (16.51%) majored in early childhood education. Table 4.2 summarizes the number of participants with various concentration tracks and majors.

Table 4.2

Majors and Concentration Tracks of the Participants

Major	Concentration Track	Participants (N=321)
Early Childhood Education		53
Elementary Education	Cultural and Linguistic Diversity	107
	Education New Literacies	8
	Mathematics	21
	Science	17
	Social Studies	12
	Special Education	64
	Performing and Visual Arts	6
Special Education		45

Measures

Mindset, calibration (i.e., self-efficacy and self-evaluation), and mathematics anxiety surveys along with graded exams and final course grades were collected to analyze the relationship between mindset and the constructs, calibration, mathematics anxiety and achievement, and the impact of mindset, calibration, mathematics anxiety on mathematics achievement. The following sections describe each of the surveys, how the surveys scores were used in the study, and the reliability of each survey.

Mathematical mindset. An eight-item survey, *Theories of Intelligence Scale – Self Form for Adults*, that was developed by Dweck's (1999) was altered to focus on students' beliefs about their mathematics intelligence instead of their intelligence in general (see Appendix L for the survey). This was accomplished by inserting math before the word intelligence in each of the items. The survey was a six-point Likert-scale survey with responses including strongly disagree, disagree, mostly disagree, mostly agree, agree and strongly agree. The survey score ranged from eight to 48 with eight representing a fixed mathematical mindset and 48 representing a growth mathematical mindset. The Cronbach's alphas (i.e. internal consistency estimates of reliability) were .89 and .93 when the surveys were administered the first and last week of the semesters, respectively, while the test-retest reliability coefficient was .70.

Self-efficacy and self-evaluation. Self-efficacy (for prediction) and self-evaluation (for postdiction) surveys were developed from the exams made by the course instructors. The surveys allowed students to estimate how well they anticipated doing (self-efficacy) or thought they did (self-evaluation) on each exam. The instructors provided the researchers with a copy of the exam that included how much each problem was worth. If a problem had multiple parts and point values were given for each part, each part had a highlighted line placed underneath that said, "I will receive ____ points on this part of the problem." If a problem only provided points for the entire problem, then the problem had a highlighted line that said, "I will receive ____ point on this problem." In either case, the participants were asked to fill in all the blanks in the highlighted lines. Also, at the end of the surveys, the students were notified of how many points the test was worth and asked to fill in the blank in the statement, "I will receive ____ points on this test." Extra space was removed so that participants would not do the problem on the survey. Also, a cover page with instructions was provided on each survey; however, the instructions for the self-efficacy and self-evaluation surveys differed slightly in the verb tense as the surveys were given to the students at different times with respect to the exams. The self-efficacy surveys were given to the students right before the exam, while the self-evaluations surveys were given the class after the exam, but before the instructors handed back the exams to the students. The Cronbach's alphas had values greater than .70 for the self-efficacy and self-evaluations surveys for each exam.

Mathematics anxiety. Van Gundy et al. (2006) created a ten-item statistics anxiety survey by modifying one of Fennema and Sherman's (1976) nine Mathematics Attitudes Scales. The ten-item survey was altered to measure mathematics anxiety in this study by changing the word statistics to mathematics. The altered survey measured anxiety related to mathematics in general, problems, and exams. The survey was a four-point Likert-scale survey with response of strongly disagree, somewhat disagree, somewhat agree and strongly agree. The survey score ranged from 10 to 40 with a larger score indicating higher math anxiety. Since the survey was administered at the beginning and end of the semester, the reliability of the survey was determined using Cronbach's alpha and test-retest reliability coefficient. The Cronbach's alphas were .93 and .94 when the surveys were administered the first and last week of the semester, respectively, while the test-retest reliability coefficient was .79.

Mathematics achievement on exams. The exams administered in the first course were created by the coordinator in conjunction with each of the instructors. For each administration of an exam, the same topics were covered by all the instructors, but some of the context of the exam problems were altered by the instructors with approval from the coordinator. The exams along with the course itself focused on mathematical content that the students would need to know for their future careers. Each test had one or two problems that not only examined mathematical content, but were scenarios problems designed to have students discuss their mathematical reasoning in a teaching situation. Most of these problems were open-ended questions with a couple of matching problems.

The exams for the third course were not coordinated between the two instructors. This caused the exams to be given at different times and the content on the exams were different as a result. The only exception to this was the final exam as the two instructors covered all the same material and the final exam was cumulative. Similar to the exams from the first course, these exams focused on mathematical content that students would need to know for their careers and contained mostly open-ended questions. The internal consistencies of the exams for both classes were reasonable with Cronbach’s alphas greater than .60 (Gall et al., 2007).

Procedure

On the first and second day of class, the lead researcher went to each class to invite students to participate in the study. The students who agreed to participate signed the consent form and filled out the mindset, mathematics anxiety and demographic surveys, in this order. They were also asked the week before the final exam to complete these surveys. Right before each exam, students were given the self-efficacy survey. They were allowed up to 10 minutes to complete the survey and as each student handed in the self-efficacy survey, the student was given the exam to have the remaining class time to complete the exam. The self-evaluation surveys were given to students the day after the exam but before the graded exam was given to the students. Students were again given up to 10 minutes to complete the self-evaluation survey. Also, before students were given their graded exams, copies of the graded exams were obtained from the instructors. After the semester ended, final course grades were obtained from the instructors by requesting the final grades for all students and as soon as possible, deleting the students who did agree to participate in the study. Sixty-three (19.63%) students provided complete data for the study.

Data Analysis

Global and local calibration accuracy and bias. The self-efficacy and self-evaluation surveys were used to measure prediction and postdiction calibration, respectively. The survey items that asked students to indicate how many points they would receive on each problem or part of a problem were used to calculate the local calibration. The last item on the surveys, which asked students to indicate how many points they would get on the entire exam, was used to calculate global calibration. Similar methods to Hacker et al. (2008b) calculations of calibration accuracy and bias were utilized in this study. However, point values were used instead of a confidence judgment using a 10-point or 100-point scale, or continuous confidence line. Additionally, the calibration scores were standardized by dividing by the total number of points each exam was worth.

To calculate local prediction calibration accuracy, the following formula was used:

$$Local\ Prediction\ Calibration\ Accuracy = \frac{\sum_{i=1}^{n} |self - efficacy\ score\ on\ question\ i - actual\ score\ on\ question\ i|}{total\ points\ for\ the\ test}$$

where *n* represents the total number of problems on the exam. Using this calculation, accuracy ranged from zero to one where zero represents a person with perfect accuracy and one represents a person with a complete lack of accuracy. To calculate local prediction calibration bias, the absolute value in the previous calculation was dropped.

Bias ranges from negative one to positive one where negative one represents a student with complete underconfidence, positive one represents complete overconfidence, and zero represents no under- nor overconfidence in a person's ability on a test.

To calculate global prediction calibration accuracy, the following formula was used:

$$Global\ Calibration\ Accuracy\ Score = \frac{|estimated\ prediction\ score\ on\ the\ exam - actual\ score\ on\ the\ exam|}{total\ points\ for\ the\ exam}.$$

Global prediction calibration bias was calculated by dropping the absolute value in the previous calculation. With these calculations, global prediction calibration accuracy and bias values had the same ranges and general meaning as local prediction calibration accuracy and bias. Postdiction calibration accuracies and biases were calculated the same way as their prediction calibration counterparts, except self-efficacy scores were replaced with self-evaluation scores in each formula.

Statistical analysis. Due to the nature of the data and the research questions, ANOVAs and regression were utilized for the analysis. The ANOVAs were used to answer the first three research questions. Due to small number of complete data for the two semesters, multiple ANOVAs were utilized for the first three research questions. The three-way ANOVAs for the first research question, and mixed ANOVAs for the second and third questions were utilized to address them. To answer the fourth research question, a correlational analysis and multiple linear regression was conducted to examine the relationship between mindset, calibration, mathematics anxiety and achievement.

Results

This section summarizes the results of the statistical analyses conducted to answer the research questions. The descriptive statistics related to the research questions are first discussed. Then the correlational analysis between the mindset, calibration, mathematics anxiety and final exam performance are examined. Lastly, the ANOVAs and multiple linear regression are discussed.

Descriptive Statistics

Table 4.3 includes the descriptive statistics of mindset, calibration accuracy, mathematics anxiety and exam performance for all the participants in the study. During both spring and fall semesters, the local prediction and postdiction calibration accuracy scores of the participants remained somewhat stable throughout the semester with the only exception being Teacher X that had students becoming more accurate from the first to second exam, and less accurate second to the final exam for both semesters. Meanwhile, the global prediction and postdiction calibration accuracy scores slightly decreased for spring semester, while the scores tended to be more stable and only slightly increasing in the fall. Students of Teachers Y and Z, who taught the third course, had lower local calibration scores than students of other teachers for the local scores both semesters. The local and global prediction and postdiction calibration bias scores of students for all the instructors during the fall and spring semesters tended around the score of zero throughout the semester, which indicated that participants were generally not too over- or underconfident in their ability. Overall, these patterns show that calibration tends to remain stable throughout these mathematics courses for both semesters. Also, teachers may influence students' calibration as students taught by different instructors had slightly different changes in calibration throughout each semester. In particular, students in Teacher X's classes tended to differ from other students in that they tended to be the least calibrated both semesters.

Table 4.3

Descriptive Summary of Mindset, Calibration, Mathematics Anxiety and Exam Performance

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Local Prediction Calibration Accuracy	Spring	First Exam	V	14	.21	.04
			W	17	.22	.02
			X	20	.24	.03
			Y	32	.18	.02
			Z	34	.14	.02
			Total	117	.19	.01
		Second Exam	V	14	.25	.04
			W	14	.21	.02
			X	22	.22	.02
			Y	26	.15	.02
			Z	36	.13	.01
			Total	112	.18	.01
		Final Exam	V	14	.23	.03
			W	14	.19	.01
			X	20	.23	.02
			Y	32	.17	.02
			Z	38	.20	.02
			Total	118	.20	.01
	Fall	First Exam	V	25	.20	.02
			W	22	.18	.01
			X	19	.26	.03
			Y	16	.16	.01
			Z	63	.17	.01
			Total	145	.19	.01
		Second Exam	V	21	.21	.02
			W	22	.18	.02
			X	16	.21	.03
			Y	16	.13	.01
			Z	59	.15	.01
			Total	134	.17	.01
		Final Exam	V	24	.24	.03
			W	14	.19	.02
			X	19	.30	.04
			Y	15	.14	.02

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
			Z	60	.18	.01
			Total	132	.21	.12
Local Prediction Calibration Bias	Spring	First Exam	V	14	-.02	.05
			W	17	.04	.03
			X	20	.09	.03
			Y	32	-.05	.02
			Z	34	-.05	.02
			Total	117	.00	.01
		Second Exam	V	14	.03	.05
			W	14	.00	.04
			X	22	.06	.03
			Y	26	-.06	.02
			Z	36	-.08	.01
			Total	112	-.02	.01
		Final Exam	V	14	.06	.04
			W	14	.02	.03
			X	20	.08	.04
			Y	32	.00	.02
			Z	38	-.05	.02
			Total	118	.01	.01
	Fall	First Exam	V	25	.02	.03
			W	22	.03	.02
			X	19	.14	.04
			Y	16	-.09	.02
			Z	63	-.03	.01
			Total	145	.00	.01
		Second Exam	V	21	-.01	.03
			W	22	.03	.02
			X	16	.00	.03
			Y	16	-.04	.02
			Z	59	-.08	.01
			Total	134	-.04	.01
		Final Exam	V	24	.13	.04
			W	14	.02	.03
			X	19	.07	.03
			Y	15	.02	.02
			Z	60	-.02	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
			Total	132	.03	.01
Local Postdiction Calibration Accuracy	Spring	First Exam	V	9	.17	.02
			W	14	.21	.02
			X	19	.23	.03
			Y	4	.14	.04
			Z	25	.11	.01
			Total	71	.17	.01
		Second Exam	V	10	.21	.04
			W	12	.19	.02
			X	22	.22	.01
			Y	19	.14	.02
			Z	27	.10	.01
			Total	90	.16	.01
		Final Exam	V	14	.21	.03
			W	13	.20	.02
			X	20	.19	.02
			Y	31	.13	.01
			Z	35	.15	.01
			Total	113	.16	.01
	Fall	First Exam	V	22	.17	.02
			W	19	.17	.01
			X	17	.26	.03
			Y	0	-	-
			Z	54	.14	.01
			Total	112	.17	.01
		Second Exam	V	20	.21	.02
			W	19	.13	.01
			X	17	.22	.03
			Y	10	.08	.01
			Z	28	.10	.01
			Total	94	.15	.01
		Final Exam	V	25	.19	.02
			W	13	.18	.02
			X	17	.26	.04
			Y	15	.14	.02
			Z	57	.15	.01
			Total	127	.18	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Local Postdiction Calibration Bias	Spring	First Exam	V	9	.01	.04
			W	14	.00	.03
			X	19	.08	.04
			Y	4	.01	.08
			Z	25	-.01	.02
			Total	71	.02	.02
		Second Exam	V	10	.06	.05
			W	12	-.04	.04
			X	22	.04	.03
			Y	19	-.03	.02
			Z	27	-.06	.01
			Total	90	-.01	.01
		Final Exam	V	14	.08	.04
			W	13	.02	.03
			X	20	.09	.03
			Y	31	.03	.02
			Z	35	-.04	.01
			Total	113	.02	.01
	Fall	First Exam	V	22	.00	.02
			W	19	.03	.02
			X	17	.13	.04
			Y	0	-	-
			Z	54	.00	.01
			Total	112	.02	.01
		Second Exam	V	20	-.01	.04
			W	19	-.01	.02
			X	17	.08	.05
			Y	10	-.02	.01
			Z	28	-.03	.01
			Total	94	.00	.01
		Final Exam	V	25	.04	.03
			W	13	.08	.04
			X	17	.15	.05
			Y	15	-.01	.02
			Z	57	.00	.01
			Total	127	.03	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Global Prediction Calibration Accuracy	Spring	First Exam	V	22	.15	.03
			W	19	.12	.02
			X	17	.17	.05
			Y	0	.08	.02
			Z	54	.12	.02
			Total	112	.13	.01
		Second Exam	V	20	.15	.04
			W	19	.11	.02
			X	17	.13	.02
			Y	10	.08	.01
			Z	28	.09	.01
			Total	94	.10	.01
		Final Exam	V	25	.12	.03
			W	13	.08	.01
			X	17	.10	.02
			Y	15	.07	.01
			Z	57	.08	.01
			Total	127	.08	.01
	Fall	First Exam	V	21	.10	.02
			W	21	.07	.01
			X	18	.14	.03
			Y	13	.10	.02
			Z	62	.08	.01
			Total	135	.09	.01
		Second Exam	V	20	.12	.02
			W	20	.09	.01
			X	14	.10	.03
			Y	15	.07	.02
			Z	57	.09	.01
			Total	126	.10	.01
		Final Exam	V	22	.17	.04
			W	14	.11	.02
			X	16	.16	.04
			Y	15	.06	.02
			Z	57	.08	.01
			Total	124	.11	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Global Prediction Calibration Bias	Spring	First Exam	V	14	-.01	.05
			W	17	.03	.04
			X	21	.12	.06
			Y	11	-.01	.03
			Z	39	-.02	.03
			Total	102	.02	.02
		Second Exam	V	14	.05	.06
			W	14	-.03	.04
			X	22	.02	.03
			Y	34	-.05	.02
			Z	38	-.09	.01
			Total	122	-.04	.01
		Final Exam	V	13	.02	.05
			W	13	.02	.03
			X	21	.04	.03
			Y	31	-.01	.02
			Z	39	-.04	.01
			Total	117	.00	.01
	Fall	First Exam	V	21	-.01	.03
			W	21	.04	.02
			X	18	.10	.04
			Y	13	-.08	.02
			Z	62	-.02	.01
			Total	135	.00	.01
		Second Exam	V	20	-.03	.04
			W	20	.02	.02
			X	14	.01	.04
			Y	15	-.05	.02
			Z	57	-.08	.01
			Total	126	-.04	.01
		Final Exam	V	22	.10	.05
			W	14	.02	.03
			X	16	.14	.04
			Y	15	.02	.02
			Z	57	-.01	.01
			Total	124	.04	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Global Postdiction Calibration Accuracy	Spring	First Exam	V	9	.12	.04
			W	13	.11	.03
			X	22	.20	.05
			Y	3	.06	.02
			Z	29	.08	.01
			Total	76	.12	.02
		Second Exam	V	9	.09	.05
			W	12	.10	.01
			X	22	.12	.02
			Y	21	.10	.04
			Z	28	.06	.01
			Total	92	.09	.01
		Final Exam	V	13	.11	.03
			W	14	.08	.02
			X	22	.09	.02
			Y	29	.05	.01
			Z	36	.06	.01
			Total	114	.07	.01
	Fall	First Exam	V	21	.08	.01
			W	18	.07	.01
			X	17	.17	.03
			Y	0	-	-
			Z	53	.07	.01
			Total	109	.08	.01
		Second Exam	V	20	.13	.03
			W	17	.08	.01
			X	17	.12	.03
			Y	10	.03	.01
			Z	28	.05	.01
			Total	92	.08	.01
		Final Exam	V	24	.13	.03
			W	14	.08	.02
			X	16	.19	.04
			Y	15	.04	.01
			Z	56	.07	.01
			Total	125	.09	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Global Postdiction Calibration Bias	Spring	First Exam	V	9	.03	.06
			W	13	-.01	.04
			X	22	.08	.07
			Y	3	-.03	.04
			Z	29	-.01	.02
			Total	76	.02	.02
		Second Exam	V	9	.05	.05
			W	12	-.03	.03
			X	22	.01	.03
			Y	21	-.09	.04
			Z	28	-.06	.01
			Total	92	-.04	.01
		Final Exam	V	13	.06	.04
			W	14	.02	.03
			X	22	.05	.02
			Y	29	.02	.01
			Z	36	-.04	.01
			Total	114	.01	.01
	Fall	First Exam	V	21	-.01	.02
			W	18	.03	.02
			X	17	.13	.04
			Y	0	-	-
			Z	53	-.01	.01
			Total	109	.02	.01
		Second Exam	V	20	-.02	.04
			W	17	-.01	.02
			X	17	.05	.04
			Y	10	-.03	.01
			Z	28	-.03	.01
			Total	92	-.01	.01
		Final Exam	V	24	.03	.04
			W	14	.06	.02
			X	16	.13	.05
			Y	15	-.01	.02
			Z	56	-.02	.02
			Total	125	.02	.01

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Exam Performance	Spring	First Exam	V	17	79.18	3.81
			W	18	77.28	3.48
			X	21	75.71	3.69
			Y	42	87.40	1.44
			Z	38	87.00	1.27
			Total	136	83.12	1.11
		Second Exam	V	17	73.76	4.40
			W	17	79.24	3.38
			X	22	76.32	2.86
			Y	41	88.91	1.37
			Z	40	94.93	.83
			Total	137	85.56	1.16
		Final Exam	V	15	72.53	4.70
			W	17	76.41	3.82
			X	22	76.00	3.04
			Y	39	85.49	1.61
			Z	40	88.83	1.16
			Total	133	81.70	1.14
	Fall	First Exam	V	26	83.15	2.86
			W	25	83.52	1.88
			X	21	72.64	4.91
			Y	19	78.24	8.04
			Z	72	85.47	1.18
			Total	163	82.31	1.37
		Second Exam	V	25	79.00	3.22
			W	25	82.16	2.08
			X	19	78.16	3.53
			Y	18	92.56	1.68
			Z	72	91.78	.93
			Total	159	86.72	.98
		Final Exam	V	26	72.15	4.23
			W	24	78.13	2.63
			X	19	67.68	4.30
			Y	17	86.01	2.71
			Z	67	83.96	1.23
			Total	153	79.25	1.25

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
Mindset	Spring	First				
		Week	V	18	25.00	2.16
			W	20	21.15	1.46
			X	22	22.23	1.40
			Y	42	19.81	.87
			Z	41	17.90	1.04
			Total	143	20.48	.58
		15^{th}				
		Week	V	8	23.88	2.46
			W	10	20.10	3.11
			X	22	21.59	1.51
			Y	35	20.06	1.34
			Z	29	18.66	1.23
			Total	104	20.29	.74
	Fall	First				
		Week	V	28	20.68	1.42
			W	25	21.20	1.53
			X	19	20.26	1.92
			Y	26	22.08	1.44
			Z	74	21.45	.74
			Total	172	21.25	.54
		15^{th}				
		Week	V	21	19.00	1.76
			W	21	22.43	1.89
			X	18	19.83	1.89
			Y	17	21.06	1.83
			Z	60	20.00	1.01
			Total	137	20.33	.68
Mathematics Anxiety	Spring	First				
		Week	V	18	28.75	1.52
			W	20	26.80	1.36
			X	21	27.24	1.22
			Y	42	27.64	.89
			Z	41	26.06	.90
			Total	142	27.15	.49
		15^{th}				
		Week	V	8	26.63	3.17
			W	10	30.80	1.80
			X	20	27.35	1.68
			Y	35	26.20	1.22
			Z	29	24.95	1.09
			Total	102	26.55	.69

Table 4.3, continued

Construct	Semester	Time	Teacher	*n*	*M*	*SE*
	Fall	First Week	V	28	28.68	1.09
			W	25	27.32	1.39
			X	19	29.37	1.48
			Y	26	28.65	.97
			Z	74	27.05	.66
			Total	172	27.85	.45
		15th Week	V	21	26.57	1.34
			W	21	28.71	1.28
			X	16	26.75	1.65
			Y	17	24.24	1.11
			Z	60	24.81	.81
			Total	135	25.85	.53

For both semesters, the difference between local prediction and postdiction calibration accuracy scores (Table 4.3) indicated that students are more accurate with their local postdiction calibration than their local prediction calibration throughout the semester, while the differences in bias scores indicated that students tend to be slightly more confident after the exam. A similar pattern appears when examining the difference between the global prediction and postdiction calibration accuracy and bias scores, except the difference between the global prediction and postdiction scores were not as large as the difference between the local scores. These relationships between prediction and postdiction calibration have been found by other researchers (e.g. Gutierrez & Price, 2017).

By going through the first and third mathematics content course for pre-service elementary teachers, students are generally becoming more growth oriented in their view of their mathematical intelligence and less math anxious. The only exception to this was for the students in the third course during the spring semester, which instead showed that students were becoming more fixed in their mindset. Fall semester students possessed a more growth mindset than spring semester at the beginning of semester, but their mindset was about the same by the end of the semester. Also, fall semester students had a larger decrease in their mathematics anxiety than spring semester students, while also having about the same starting mathematics anxiety. Meanwhile, for both semesters, the exam performance of students tended to increase from the first to second exam and decrease from the second to third exam, final exam. The differences between the second and final exam scores may be due to the final exams were all cumulative. The instructors that had students not following this pattern were Teachers V, W and X during the spring semester, and Teacher V during the fall semester. They had exam performance decreasing through the semesters.

Correlational Analyses

Table 4.4 presents the zero-order correlations for mindset, local and global prediction calibration accuracy and bias, mathematics anxiety and exam scores at the end of the semester for participants. The correlation between the calibration measurements were all significantly related but only local and global prediction calibration accuracy, and local and global prediction calibration bias were correlated at positive strong levels. Mindset only significantly correlated positively with local prediction calibration accuracy, but at a weak level. Meanwhile, mathematics anxiety correlated significantly with mindset and calibration measurements, except global prediction calibration bias, in a positive manner. Mathematics anxiety correlated moderately with local prediction calibration accuracy and mindset, while the other three calibration measures correlated weakly. Lastly, the correlations between the exam scores and the other six variables were significant and negative. Final exam scores correlated with local calibration accuracy at a strong level, with local calibration bias, global calibration accuracy and bias, and mathematics anxiety at a moderate level, and mindset at a weak level. Given the correlational relationship between final exam and the other variables, these relationships are examined more closely in the multiple linear regression analysis.

Table 4.4

Correlations of the End-of-the-Semester Mathematical Mindset, Prediction Calibration, Mathematics Anxiety and Exam Performance

Measures	LCB	GCA	GCB	MS	MA	Exam
Local Calibration Accuracy (LCA)	-	.72**	-	.21**	.43**	-.76**
Local Calibration Bias (LCB)	-	-	.89**	.03	.15*	-.66**
Global Calibration Accuracy (GCA)		-	-	.10	.23**	-.62**
Global Calibration Bias (GCB)			-	-.02	.09	-.67**
Mindset (MS)				-	.46**	-.26**
Math Anxiety (MA)					-	-.48**

*$p < .05$, **$p < .001$

Analysis of Variance

To investigate the relationship between mindset, calibration, mathematics anxiety and achievement, several ANOVAs were administered. Due to the small amount of complete data collected throughout both semester, simpler ANOVAs models were chosen for analysis instead of more complex ANOVAs and MANOVAs to ensure that group sizes were adequate, more participant data were utilized in answering each research question, and assumptions were satisfied. Additionally, the Greenhouse-Geisser correction was used for the within-subject effect in the mixed ANOVA analyses when the sphericity assumption was violated.

To examine the relationship between mindset and mathematics anxiety, two three-way ANOVAs were conducted. The three-way ANOVAs examined the relationship between students' mathematics anxiety (low, moderate, high) on mindset during the first and last week of classes accounting for their instructor (Teacher V, Teacher W, Teacher X, Teacher Y, Teacher Z) and semester (spring, fall). The students' mathematics anxiety levels were determined by low anxiety representing a score of 10 to 20 on the survey, moderate anxiety representing 21-29, and high anxiety representing 30-40. The three-way ANOVA with students' initial mindset and mathematics anxiety had a significant interaction effect between semester and mathematics anxiety level, $F(2, 301) = 3.62$, $p = .03$. Using a Bonferroni correction at $\alpha = .05$, simple main effects analysis showed that mindset differed significantly between low and high mathematics anxiety during the spring ($p = .01$) and fall semester ($p < .001$), and moderate and high mathematics anxiety during fall semester ($p < .001$). This indicates that low mathematics anxious students' mindset during spring (M = 17.84, SD = 8.48) and fall (M = 16.03, SD = 9.39) was significantly more growth oriented than the high mathematics anxious students during spring (M = 22.97, SD = 7.08) and fall (M = 25.54, SD = 6.89), respectively. During fall semester, students with a moderate level of mathematics anxiety (M = 18.64, SD = 7.47) possessed a more significant growth mindset than students with a high level of mathematics anxiety.

The three-way ANOVA with students' end-of-the-semester mindset and mathematics anxiety had only a statistical significant main effect of mathematics anxiety level, $F(2, 233) = 23.95$, $p < .001$. The main effects of teacher ($F(4, 233) = .05$, $p =. 99$) and semester ($F(1, 233) = .16$, $p = .69$) were not significant. Post hoc comparison using Tukey HSD test at $\alpha = .05$ showed that high math anxious students (M = 24.80, SD = 7.96) are significantly more fixed mindset than low (M = 16.06, SD = 6.07) and moderate (M = 18.65, SD = 6.71) mathematics anxious students.

To examine the relationship between mindset and calibration, mixed ANOVAs were conducted. This examined global and local prediction and postdiction calibration accuracy and bias over time between three levels of average mindset (strong growth-oriented mindset, growth-oriented mindset, fixed-oriented mindset) accounting for instructor and semester. Participants were considered a strong growth-oriented mindset if their average semester mindset score was between eight and 18.5, a growth-oriented mindset if their average semester mindset score was between 19 to 28, and a fixed-oriented mindset if their scores was 28.5 or above.

For the global prediction calibration accuracy ANOVA, the interaction effect between average mindset level and semester was significant, $F(2, 128) = 3.15$, $p < .05$, while the main effect of teacher was not significant, $F(4, 128) = 2.13$, $p = .08$. Simple main effects analysis showed that students with fixed mindset orientation were significantly less accurate in their global prediction calibration than the strong-growth mindset ($p < .01$) and growth mindset students ($p < .01$) during spring semester. Additionally, during spring semester, growth mindset students were more accurate in their global prediction calibration than the fixed mindset students, but not at a significant level. This pattern also occurred during the fall semester, but not with any significance.

For the mixed ANOVA with global prediction calibration bias, the main effects of time (F(1.84, 241.61) = 13.76, p < .001), teacher (F(4, 131) = 4.30, p < .001), and average mindset level (F(2, 131) = 4.99, p < .01) were significant. Post hoc comparison using Tukey HSD test at $\alpha = .05$ of time showed that students were more confident on the final exam (M = .03, SD = .18) compared to the first exam (M = -.01, SD = .15) and second exam (M = -.04, SD = .17) at a significant level. Teacher X's students (M = .04, SD = .10) were significantly more confident than Teacher Y's (M = -.04, SD = .10) and Z's (M = -.05, SD = .10) students. Strong growth-oriented mindset students (M = .03, SD = .10) were significantly more confident than growth-oriented mindset students (M = -.28, SD = .10), and non-significantly more confident than the fixed-oriented mindset (M = -.26, SD = .10).

For the mixed ANOVA with global postdiction calibration accuracy, the main effect of teacher (F(3, 83) = 3.12, p = .03), and the interaction effect between semester and mindset orientation (F(2, 83) = 3.83, p = .03) were significant. Post hoc comparisons of teacher using Tukey HSD test at $\alpha = .05$ found that Teacher X's students (M = .13, SD = .07) were less accurate in global postdiction calibration than Teacher Z's students (M = .08, SD = .08). Simple main effects analysis indicated growth-oriented students were significantly more accurate than students with a fixed-oriented mindset during the fall semester (p < .01). Strong growth-oriented students were also more accurate than fixed mindset students, but not significantly.

For the global postdiction calibration bias ANOVA, the main effect of teacher ($F(3, 84) = 4.19$, $p < .01$) and the interaction between time and average mindset level ($F(4, 168) = 3.00$, $p = .02$) were significant. Post hoc comparisons using Tukey HSD of teacher showed Teacher X's students (M = .05, SD = .11) were significantly more confident than Teacher Z's students (M = -.05, SD = .12). Simple main effects analysis found that the strong growth-oriented mindset students were significantly more confident than the fixed-oriented mindset students for the second exam ($p = .01$).

For the local prediction calibration accuracy ANOVA, the main effect of teacher ($F(4, 146) = 4.02$, $p < .01$) and average mindset level ($F(2, 146) = 5.61$, $p < .01$) were significant. None of the interaction effects and other main effects were significant at the significance level of .05. Post hoc comparisons of time using Tukey HSD test showed that Teacher X's students (M = .23, SD = .08) were significantly less accurate than Teacher Y's (M = .16, SD = .08) and Z's (M = .18, SD = .08) students. Also, the strong growth-oriented mindset students (M = .17, SD = .08) were more accurate in their local prediction calibration than the fixed-oriented mindset students (M = .23, SD = .08).

For the local prediction calibration bias ANOVA, the interaction effect of time ($F(1.92, 281.54) = 13.00$, $p < .001$) and teacher ($F(4, 147) = 9.56$, $p < .001$) was the only significant factors at the .05 significant level. Post hoc comparisons of time using Tukey HSD showed that students were significantly more confident on the final exam (M = .00, SD = .10) compared to the first exam (M = -.02, SD = .11) and second exam (M = -.03, SD = .12). Tukey HSD test illustrated that students of Teacher Z (M = -.06, SD = .10) was significantly less confident than students of Teachers V (M = .04, SD = .10), W (M =

.02, SD = .09), and X (M = .05, SD = .09). Additionally, Teacher X's students were more confident than Teacher Y's students (M = -.03, SD = .10).

For the local postdiction calibration accuracy ANOVA, the main effect of teacher (F(4, 81) = 5.64, p = .001) was significant. Post hoc comparisons of teachers using Tukey HSD test illustrated that Teacher X's students (M = .23, SD = .09) were more confident than Teacher Z's students (M = .14, SD = .09).

For the local postdiction calibration bias ANOVA, the main effect of time (F(2, 158) = 7.30, p < .001) and teacher (F(3, 79) = 7.62, p < .001) were the only significant factors. Post hoc comparisons of time showed that students were significantly more confident on the first exam (M = .04, SD = .16) compared to the second exam (M = -.03, SD = .18). Tukey HSD test illustrated that students of Teacher X (M = .09, SD = .11) was significantly more confident than students of Teachers V (M = -.01, SD = .12), and Z (M = -.05, SD = .13).

To examine the relationship between mindset and mathematics achievement, a three-way ANOVA was conducted. This was accomplished by investigating the change in mindset between students' final course grades (A, B, C/D/F) accounting for semester and instructor. The ANOVA showed that only final course grade was a significant predictor, F(2, 226) = 4.90, p < .01. The post hoc analysis using Tukey HSD test indicated that B students (M = -1.42, SD = 5.91) had a significantly different change in mindset than the C/D/F students (M = 2.18, SD = 5.89); in particular, B students' mindset became more growth oriented, while C/D/F students became more fixed oriented. The A students (M = -.19, SD = 6.83) also became more growth oriented, but the change was smaller than the B students.

Multiple Regression Analysis

Multiple linear regression was used to investigate the influence of mindset, calibration and mathematics anxiety on mathematics achievement. This was investigated by examining the influence of end-of-the-semester mathematical mindset, local and global prediction calibration, and mathematics anxiety on final exam performance accounting for instructor and semester. A step-up strategy was implemented to build the regression model. The starting model included four indicator variables to identify the five instructors, mindset, mathematics anxiety, and local and global prediction calibration accuracy and bias for the final exam. To avoid multicollinearity between mindset, mathematics anxiety and calibration variables, and their corresponding interaction terms, the variables were centered.

Table 4.5 shows the parameter estimates for mindset, mathematics anxiety, calibration variables and indicator variables for the instructors along with the significant interaction terms of local calibration accuracy and Teacher X, local calibration bias and semester, global calibration accuracy and Teacher V, global and local calibration bias, global calibration bias and mathematics anxiety, mathematics anxiety and Teacher W, and mathematical mindset and Teacher W. The regression model indicated the predictors explained 90.5% of the variance ($R^2 = .90$, $F(18, 169) = 83.42$, $p < .001$).

Table 4.5

Parameter Estimates for Final Multiple Linear Regression Model

Variable	Estimate	*SE*
Intercept	81.90***	.79
Local Prediction Calibration Accuracy	-75.56***	5.25
Local Prediction Calibration Bias	-25.76***	5.98
Global Prediction Calibration Accuracy	-11.85	8.29
Global Prediction Calibration Bias	-12.51	6.59
Mathematical Mindset	-.07	.05
Mathematics Anxiety	-.11	.06
Teacher V	-2.40*	1.09
Teacher W	-1.05	1.48
Teacher X	-2.13*	.98
Teacher Y	1.25	.92
LCA X Teacher X	-41.77***	10.31
LCB X Semester	-16.90**	5.94
GCA X Teacher V	-35.95***	10.05
GCB X LCB	114.99***	22.87
GCB X MA	1.23*	.50
MA X Teacher W	-.98*	.31
MS X Teacher W	.38*	.19

* $p < .05$, ** $p < .01$, *** $p < .001$

The regression model indicates that as participants' local prediction calibration accuracy scores decrease by .05 (or the absolute difference between perceived and actual performance decreases by 5 points on a 100-point exam), their exam scores increases by 5.87% for Teacher X and 3.78% for the other instructors. Meanwhile, as participants' local prediction calibration bias scores decrease by .05 (or their confidence decreases by 5 points on a 100-point exam), their exam performance increases by 4.16%, 2.73%, 1.86%, 1.58%, 1.00%, and .71%, and a decrease by .15% and 1.59% for spring semester at global prediction calibration bias of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively. For example, for a local prediction calibration bias score decrease of .05 at a global prediction calibration bias of -.50 during spring semester, a student's exam performance increases by 4.16%. For fall semester, a decrease in the bias score by .05 led to an increase in exam performance of 5.01%, 3.57%, 2.71%, 2.42%, 1.85%, 1.56%, .70%, and a decrease in exam performance of .74% at global prediction calibration bias values of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively.

For global prediction calibration accuracy, a decrease of .05 leads to an increase of 2.39% for Teacher V and .59% for the other teachers. Given a mathematics anxiety score of 10, a decrease of .05 in global prediction calibration bias causes an increase in exam scores of 2.85%, 1.41%, .55%, .26%, and a decrease of .31%, .60%, 1.46% and 2.90% at local prediction calibration bias values of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively. Assuming a participant has a mathematics anxiety score of 25, a decrease of .05 in global prediction calibration bias leads to an increase in exam scores of 1.93% and .49%, and a decrease of .37%, .66%, 1.23%, 1.52%, 2.38% and 3.82% at local prediction calibration bias values of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively. Lastly, with a mathematics anxiety score of 40, a decrease of .05 in global prediction calibration bias causes an increase in exam scores of 1.01%, and a decrease of .43%, 1.29%, 1.58%, -2.15%, 2.44%, 3.30% and 4.74% at local prediction calibration bias values of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively.

For mathematical mindset, as a participant's mindset score decreases by 1, his/her exam performance increases by .45% for Teacher W and .07% for the other instructors. For Teacher W, as a participant's mathematics anxiety decreases by 1, his/her exam performance decreases by .26%, .56%, .75%, .81%, .93%, .99%, 1.18% and 1.49% at global prediction calibration bias values of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively. Meanwhile, for other teachers, as a participant's mathematics anxiety decreases by 1, his/her exam performance increases by .73%, .42%, .23%, .17%, .05%, and decreases by .01%, .20% and .51% at global prediction calibration bias values of -.50, -.25, -.10, -.05, .05, .10, .25, and .50, respectively.

Discussion

The purpose of the study presented in this paper was to investigate the relationship between mindset, calibration, mathematics anxiety and mathematics achievement for pre-service elementary teachers. This was accomplished by focusing on the connection between mindset and the constructs, global and local calibration accuracy and bias, mathematics anxiety, exam performance and final course grade data, which was analyzed using ANOVAs and multiple linear regression.

Research Question 1 Answer

For the first research question, the results of the difference in mindset between low, moderate and high math anxious students accounting for instructor and semester were within expectations. At the beginning of the semester, low and moderate mathematics anxious students had a more growth mindset compared to highly anxious students for both semesters. At the end of the semester, students with low and moderate levels of anxiety of mathematics possessed a more growth mindset than high mathematics anxiety students. This aligns with the theoretical assumptions discussed in the theoretical framework section, in which lower mathematics anxiety should correspond to a more growth mindset. Mathematics anxiety may be more of a motivator for growth mindset students as these students are more likely to focus on content they are anxious about to ensure they understand the material in order to be successful in their learning. In turn, this reduces their overall mathematics anxiety as they feel more prepared for class and tests. For fixed mindset students, mathematics anxiety may act more like a demotivator for learning. For these students, mathematics anxiety related to a concept means that they do not know the concept well enough and could fail to understand the concept. As a result, they are more likely to avoid the concept as they want to avoid the possibility of failure to ensure that they feel and are viewed as smart. Also, a growth mindset creates resilience in the mathematics (Yeager & Dweck, 2012), which leads to a decrease in mathematics anxiety (Johnston-Wilder et al., 2015).

Research Question 2 Answer

The second research question is related to the relationship between mindset and calibration by investigating local and global calibration accuracy and bias over time based on students' average mindset for the semester. The results of the mixed ANOVAs indicate that the type of teacher (i.e. different teachers), content covered (i.e. different courses and different topics on each exam, and different exam lengths), and beliefs about mathematical intelligence along with the semester (i.e. different levels of mindsets during different semesters) can influence pre-service elementary teachers' calibration. The course instructors tended to have influence on students' calibration accuracy and bias, except for prediction global calibration accuracy. This is mainly due to Teacher X's students being less calibrated than the other instructors. There are several reasons that could contributed to this result, including teaching style, student and teacher interactions during class, and feedback structure. Even though previous research studies have shown certain types of feedback given to students can lead students to be better calibrated (Hacker et al., 2000; Nietfeld, et al., 2006; Labuhn et al., 2010), some other studies provided contradicting results (e.g., Nietfeld et al., 2005; Schraw et al., 1993). Besides feedback potentially assisting students to calibrate, group interactions on practice problems can improve calibration (Bol et al., 2012; Gutierrez & Price, 2017). These possible influences on pre-service elementary teachers' calibration were not examined in this study, but could be examined in a future study.

Only calibration bias seems to be influenced by the content on an exam and the length of the exams (i.e., first, second and final exams). For global postdiction calibration bias, growth mindset students were more confident than the fixed mindset students for the second exam. As discussed in the literature review, this may be due to growth mindset students focusing more of their studying on the concepts they do not know well enough for the exam than the fixed mindset students. For the other calibration biases (i.e., global prediction, local prediction and local postdiction), students were more confident on the first exam than the second exam. Also, global and local prediction calibration biases show that students were more confident on the final exam compare to the second exam. Even though all the tests in this study covered topics within the domain of mathematics, the tests covered different topics within mathematics, which may account for the differences between the calibration biases on each exam. However, the fact that students were generally more confident on the first exam compared to the other exams in both semesters indicates that the different topics covered on different exams may not account for all the differences. More confidence on the first exam may be due to that students did not know what to expect on the first exam in these courses, and mathematics students tend to overestimate their abilities when calibrating (Dinsmore & Parkinson, 2013; Pajares, 1996; Pajares & Kranzler, 1995; Pajares & Miller, 1994).

For global prediction and postdiction calibration accuracy, mindset and semester interacted with each other. During the spring semester, students with a fixed mindset orientation were less accurate in their global prediction calibration than the students with a more growth mindset orientation. A similar result occurred for global postdiction calibration accuracy for the fall semester. For local prediction calibration accuracy and global prediction calibration bias, mindset orientation was a significant factor. In particular, a more growth mindset indicated a tendency to more accurate in local prediction calibration accuracy. For global prediction calibration bias, the strong growth-oriented mindset students were more confident than the more fixed mindset groups, but more importantly, the strong growth-oriented mindset students' biases scores were closer to zero than the other two. This indicates that on the bias scale the strong growth-oriented mindset students are more calibrated; in other words, these students are slightly over- or underconfident when compared to the more fixed mindset groups. Overall, these calibration bias results indicate that a more growth mindset student is more likely to be calibrated in his/her biases. These results follow the theoretical connection between calibration and mindset as discussed in the literature review. As mentioned, Freund and Kasten (2011) and O'Keefe (2013) discussed that a more growth mindset allows students to more deeply and critically evaluate their errors on problems to improve their understanding, while more fixed mindset students will attempt to evaluate their errors in such a way that protects their self-image as smart and capable people. This allows the growth mindset students' actual ability to more closely align with their perceived ability because students tend to be overconfident in their ability as indicated by Dinsmore and Parkinson (2013) and Pajares's work.

Research Question 3 Answer

The third research question investigated the relationship between mindset and mathematics achievement. A and B students' mindset changed to a more growth mindset, while the C/D/F students' mindset became more fixed. This indicates that pre-service elementary teachers who tend to do well in mathematics context courses develop a more growth mindset, while those that do not do well develop a more fixed mindset. Considering the existing literature that indicated a more growth mindset leads to better mathematics performance (e.g., Aronson et al., 2002; Blackwell et al., 2007; Claro et al., 2016; McCutchen et al., 2016), it is not surprising that higher performing students develop more growth mindset as their efforts have allowed them to achieve reasonably well. Meanwhile, the lower performing students may see that their efforts were not worthwhile as they did not do as well as hoped, which might have led to a more fixed mindset (Dweck, 2006).

Research Question 4 Answer

For the fourth research question, the predictive nature of mindset, calibration and mathematics anxiety on mathematics achievement was examined by exploring the connection between mindset, prediction calibration, mathematics anxiety and exam performance on the final exam. The correlations between calibration measurements and the final exam score indicate that as students become more accurate and underconfident in their calibration, their exam scores increase. Previous calibration research has found similar results for correlations of accuracy and bias, and their correlations with respect to exam performance (Chen, 2003; Chen & Zimmerman, 2007; Ozsoy, 2012).

The correlations with the ANOVAs seem to indicate that mindset may influence mathematics anxiety, which in turn, can affect calibration, and all three of these constructs together can influence mathematics performance. In particular, some of the correlations indicate that as students become more growth mindset oriented, their mathematics anxiety decreases, and global calibration accuracy increases. The decrease in participants' mathematics anxiety may lead them become more calibrated. Additionally, the decrease in mathematics anxiety, students becoming more calibrated and more growth mindset oriented can all lead to an increase in final exam performance. This possible interpretation of the data fits within the mindset theoretical framework, and with the research that examined the relationship of mathematics achievement with mindset, calibration and mathematics anxiety which was discussed earlier. The metacognitive model by Van Overschelde's (2008), and Nelson and Narens (1990, 1994) provides insight to the relationship of mathematics anxiety and calibration. Mathematics anxiety can affect students' metacognitive monitoring and control. For metacognitive monitoring, mathematics anxiety can inhibit students' working memory, which limits students' mathematical problem solving, critical thinking, and ability to calibrate (Ashcraft, 2002; Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Justicia-Galiano et al., 2017; Novak & Tassell, 2017; Raghubar et al., 2010). This occurs due to the amount of information stored in students' working memory being reduced by their mathematics anxiety, especially for students with high working memory capacity (Beilock & Carr, 2005; Ramirez et al., 2013; Vukovic et al., 2013). By not possessing all the necessary information for a problem, students make their calibration judgment within the dynamic model at the meta-level using an incomplete picture. For metacognitive control, mathematics anxiety can act as an internal perceived constraint that limits students' control actions. In particular, when studying and working on problems, students may not study appropriately, and fail to solve problems they can solve. Thus, mathematics anxiety can lead the student to be less calibrated.

The multiple linear regression supported some of the indications from the correlations. For mathematical mindset, as students' mathematical mindset becomes more growth oriented, their exam performance increases, but the increase was much larger for Teacher W than the other instructors. This result corresponds to existing literature that growth mindset promotes better mathematics achievement (e.g., Aronson et al., 2002; Blackwell et al., 2007; Good et al., 2003); in particular, this supports Claro et al.'s (2016) and McCutchen et al.'s (2016) findings that mindset was a significant predictor of mathematics achievement. The interaction between mindset and Teacher W indicates that students' mindset can be influenced by an instructor to improve students' mathematical performance, which Boaler (2016), Dweck (2006) and Leslie et al. (2015) also highlighted in their studies.

For mathematics anxiety, Teacher W's students had a smaller increase or larger decrease in exam performance than the other instructors' students as students became more confident globally. This shows that the teacher and global calibration bias can influence the link between mathematics anxiety and exam performance for pre-service elementary teachers. The instructors of the mathematics content courses can mediate the relationship between mathematic anxiety and achievement through the structure of the course (e.g., Brady & Bowd, 2005; Lorenzen, 2017; Unglaub, 1997), not providing positive experience in mathematics classes (e.g., Bekdemir, 2010; Uusimaki & Nason, 2004), and not providing students with positive interactions (e.g., Brady & Bowd, 2005; Unglaub, 1997). The interaction between mathematics anxiety and global calibration bias fits within Nelson and Narens's (1990, 1994) metacognitive model through metacognitive monitoring. In particular, mathematics anxiety can lower the confidence judgements that a student utilizes when deciding what to study as mathematics anxiety and confidence measurements have been found to be negatively correlated (Ashcraft, 2002; Jameson & Fusco, 2014; Legg & Locker, 2009; Malpass et al., 1999). Lower confidence for students may cause them to study for an exam more than originally intended, which can lead them to study topics they do not know well enough. This can lead to better exam performance.

In general, the influence of prediction calibration on exam performance matched the correlation analysis, which corresponds to the research discussed in the literature review. However, the magnitude of the influence of prediction calibration is difficult to determine as there were interactions between local calibration accuracy and Teacher X, local calibration bias and semester, global calibration accuracy and Teacher V, and global calibration bias and local calibration bias, and global calibration bias and mathematics anxiety. Students being more accurate in their local and global calibration led to an increase in exam performance, but for Teacher X and Teacher V, respectively, this led to a larger increase in performance. For increasing local calibration bias scores, fall-semester students had larger increase or smaller decrease in exam performance than spring-semester students as students became more confident globally. For increasing global calibration bias scores, lower mathematics anxious students had a larger increase or smaller decrease in exam performance than higher mathematics anxious students as students became more confident locally.

The possible reasons for the interactions between calibration and instructors, calibration and mathematics anxiety, and global calibration bias and mathematics anxiety have been discussed previously. The significant interaction between local calibration bias and global calibration bias may be due to how students determined their point value for how well they would do on the exam. Some students mentioned that they just summed their individual problem point estimates to get their exam point estimate (global pre- or post-diction scores). Given that both measurements are measuring students under- and overconfidence on the exam with global bias measuring this for the entire exam and local bias measuring this for each item, the interaction between the two measurements is not surprising. For the interaction between local calibration bias and semester, the fall semester students tend to be more growth mindset oriented than the spring semester students. The fall semester students may be more willing to work with challenging content more than the spring semester students; in other words, fall students may be more willing to work with content they are not confident that they understand. As a result, the fall semester students are more likely to perform better on those problems than the spring students.

Limitations

There were several limitations of this study, which involved when the end-of-the semester mindset and mathematics anxiety was measured, the wording of the calibration surveys, and collection of self-evaluation surveys. The first limitation is related to when the mindset and mathematics anxiety surveys were administered in each class. They were given one or two class days before the final exam, while in other studies researchers administered the mindset and math anxiety surveys at the time of their other measurements. As a result, the mindset and mathematics anxiety scores used in the multiple linear regression may not represent the pre-service teachers' measures when taking the test. Several students mentioned that they start studying for a test at most one day before an exam. Those that had not studied before taking the surveys may not have known what they knew or did not know of the material for the test, and the influence of effort on their understanding of the content. By the time they took the exam, their mindset and mathematics anxiety could have changed depending on how well they believed they learned the material. The main reason for not measuring mindset and mathematics anxiety right before the final exam was due to concern from the mathematics coordinators and instructors of the pre-service elementary teacher courses. They felt that collecting the mindset and mathematics anxiety data along with the self-efficacy surveys right before the exams would take too much time away from the exam.

Also, the mathematics anxiety survey could have caused students to more actively think about their mathematics anxiety when taking the exam and, as a result, lead them to perform worse on the exams.

Another limitation is related to the wording of the items on the self-efficacy and self-evaluation surveys. The surveys asked students to use their confidence and knowledge of their instructor to estimate how many points they think they would obtain on each item and overall for each test. Hacker et al. (2008b) mentioned that the common methods for measuring confidence were a confident judgment using a 10-point or 100-point scale, or confidence line. Although, Alexander (2013) mentioned that there is no fixed method for measuring calibration, and Bol et al. (2012) did use predicted and postdicted test scores for calculating global calibration. The format of the exam questions made it difficult to utilize the more common methods of measuring confidence as most questions were open-ended with a few multiple choice or matching problems. Therefore, the current findings related to calibration may not correspond to other calibration accuracy and bias findings.

The issues related to collecting self-evaluation surveys are due to an error by an instructor, and a couple of class's situation after the second exam. For both spring and fall semesters, an instructor for the third mathematics content course mistakenly put up the first exam scores on Canvas's grading system for students to see before the self-evaluation surveys were obtained. As a result, most students in that class already knew their overall performance on the exam, while at the same time, some of them ensured that their performance estimate for each item summed to their exam score. To not bias the data, the postdiction calibration scores calculated from these self-evaluation surveys were not used in the analysis. Due to the classroom situation the day after the second exam, the self-evaluation surveys were delayed by a class day for two classes in the spring semester. This may have caused students to not remember the problems and their work as clearly as the students who did the survey the class after the exam. Thus, these students' postdiction calibration scores may not be as accurate as other classes' scores.

Implications

From this study, there are several implications for educational practices and research. An educational implication is to advocate for metacognition training and group work in the classroom as a way to improve students' calibration and understanding of mathematics. The findings from Cardelle-Elawar (1995), Bol et al. (2012), Kramarski and Mevarech (2003), Kramarski and Dudai (2009), and Kruger and Dunning (1999) suggest that metacognitive training, which includes the skills necessary for calibration, is beneficial to students' understanding and performance. They found that those who received metacognitive training significantly improve their performance compared to students who did not receive such a training. Additionally, Bol et al. (2012), Kramarski and Mevarech (2003) and Kramarski and Dudai (2009) found that group work improved student achievement, while metacognitive training and group work combined delivered the best environment for improving student performance. In relation to the influence of metacognitive training and group work on calibration, Bol et al. (2012) also found that students who utilized their group metacognitive guidelines displayed the greatest global calibration accuracy. Due to a shift from teacher-centered to student-centered teaching practices, accurate monitoring and control of students' learning is becoming increasingly important (Kostons & de Koning, 2017).

Another method to improve students' calibration and performance may be to provide students with an opportunity to practice calibration throughout the semester along with feedback that allows the students an opportunity to self-reflect on their knowledge and studying strategies. In conjunction with this practice, the instructors should promote a more growth mindset in the students using instructional methods discussed in Dweck (2006), Dweck (2015) and Boaler (2016). Nietfeld et al. (2006) found weekly monitoring practice on quizzes with feedback helped students to become better calibrated in a psychology course, while some researchers (e.g., Nietfeld et al., 2005; Schraw et al., 1993) suggest that feedback does not help. Feedback may only be useful when students attempt to self-reflect because self-reflection can help students improve their calibration and performance in mathematics (DiGiacomo & Chen, 2016; Ramdass & Zimmerman, 2008; Zimmerman et al., 2011). Students' mindset will assist in determining their likelihood for reflection. Given the characteristics of growth mindset students, they are more likely to reflect using feedback to improve their understanding as the mathematics anxiety due to their mistakes on the exam are more likely to be seen as a motivator for their learning. Fixed mindset students are more likely to ignore the feedback as it may indicate they are not smart, and they want to preserve their feeling of being intelligent. Also, the type of feedback provided by instructors could influence students' ability to reflect and improve their understanding. Labuhn et al. (2010) and Hacker et al. (2000) found that individualize and social comparison feedback possibly with accompanying graphic visuals are useful for improving calibration. Thus, researchers should investigate whether calibration practice in the mathematics classroom in conjunction with practices developing a more growth mindset for students would improve students' calibration and performance, and what types of teacher feedback work better in that environment.

Based on the suggestions of Chang and Beilock (2016) and Herts and Beilock (2017), and the findings of this study, further investigations of the possible influence of mindset and calibration on the link between mathematics anxiety and achievement should be conducted. In particular, researchers could examine the casual relationship between these constructs. One interesting result that should also be investigated more is the fact that most pre-service elementary teachers who were mostly females tended to be growth mindset oriented, while Boaler (2014) mentioned that girls tend to be more fixed mindset oriented. Dweck (2015) mentioned that some teachers have developed a false growth mindset belief; in other words, teachers are saying they promote growth mindset in their class as they belief that is the correct answer for the mindset question, but their action say otherwise. As mindset is become more known in education, are pre-service elementary teachers developing a false growth mindset belief for themselves? From the differences in instructors in the results, one should explore (by conducting a mixed-methods study) the connection between instructor's beliefs, the classroom dynamic, and interaction between the two.

CHAPTER V

DISCUSSION

The purpose of this dissertation was to investigate the relationship among pre-service elementary teachers' calibration constructs of mindset, mathematics anxiety, and mathematics achievement. To accomplish this purpose, I conducted three studies. Chapter I provided a summary for the need of this research and examined existing studies for each construct and possible relationships between them. Chapters II, III, and IV are studies that examined the relationship between the constructs in pre-service elementary population. In the following sections, I synthesize the results of the three studies to answer the overarching research questions that guided the dissertation; discuss the implications for teaching, research, and policy; limitations of the studies; and suggestions for future research.

Summary of the Studies

Pre-service elementary teachers play an important role in shaping our next generation. Beilock et al. (2010), Gunderson et al. (2012), and Jackson and Leffingwell (1999) stated pre-service elementary teachers' mathematics anxiety not only impacts these teachers but can also be transferred to their students, which could result in inhibiting students' learning and performance. Hence, it is important to understand what factors relate to the mathematics anxiety and achievement relationship and how mathematics educators can address this concern in mathematics content classrooms (Chang & Beilock, 2016; Hembree, 1990; Ramirez et al., 2018).

In this particular dissertation, I focused on two possible constructs, mindset and calibration, that seemed to be related to mathematics anxiety and achievement of pre-service elementary teachers. Calibration, one of the metacognitive constructs, is defined as a measure of a person's perceived performance on a task compared to the actual performance on that task (Hacker et al., 2008b; Nietfeld et al., 2006). To further the call for study of metacognition outside the laboratory setting by Nelson and Narens (1994) and Carroll (2008), Hacker et al. (2008b) suggested studying calibration in the classroom setting. In particular, they noticed the need to study calibration in the classroom because calibration used in studying and taking exams in a classroom setting has different underlying motivations, goals, and constraints for students than calibration in a laboratory study. This is in part due to the particular course students are taking, the positive and negative emotions they bring into and are elicited by the course, and the effect exams have on their course grade. Thus, studying calibration in the classroom setting is also related to students' self-regulation learning process. Self-regulated learning can be defined through several differing metacognitive models. The metacognitive and self-regulated learning model utilized for this study was Nelson and Narens's (1990,1994) model, which was expanded upon by Van Overschelde (2008).

In Chapters I, II, III and IV, the metacognitive model by Nelson and Narens (1990, 1994) provided theoretical implications about the relationship among mindset, calibration, and mathematics anxiety. Hacker et al. (2008b) discussed Nelson and Narens's memory stages framework and the placement of calibration within it.

Calibration judgments occur after acquisition and retention but might be made either before or after the retrieval of relevant knowledge. Koriat et al. (2006) placed judgments for predicting calibration during or after the retrieval stage within metacognitive monitoring and control while Hacker et al. placed the judgements for postdiction calibration after recall.

Van Overschelde (2008) extended Nelson and Narens's (1990, 1994) metacognition model through the inclusion of perceived constraints such as mathematics anxiety, time constraints, and expectations of and motivations for a class and exam. Perceived constraints influence people's metacognitive control by limiting what actions they take at the cognitive level. For example, students who have only an hour left to study before they must take an exam must make a choice of what actions to take in that hour in terms of their studying. Some students might choose the remaining time studying materials they are not sure of while others might focus on material they know and just want to review. Other students might choose to take that time to relax instead of studying as they are becoming very mathematically anxious. Their choices depend not only on the time constraint but on their mathematics anxiety and motivations for the course and exam.

How much students' mathematics anxiety constrains their metacognitive control actions depends on whether mathematics anxiety acts as a motivator or demotivator for further studying. Mindset might be a world view that explains whether mathematics anxiety is a motivator or demotivator through the influence mindset has on the meaning of success, failure, and effort. Mindset could also play a role in developing students' calibration. For example, when students prepare for a test, they consciously or unconsciously make judgements about what they know and what they do not know well enough. Using that information, growth mindset students might tend to focus on what they have missed on previous assignments, exams, and in class materials to improve their understanding. Meanwhile, fixed mindset students might tend toward focusing on the content they already know well enough to show they can be successful. As a result, growth mindsets will have a better idea of the alignment between their actual and perceived ability while fixed mindsets will only have a better idea of such alignment for the material they believe they know. This means growth mindset students are more likely to calibrate better than fixed mindset students.

The three constructs of calibration, mindset, and mathematics anxiety affected students' mathematics achievement as described in Chapters I, II, III, and IV. Additionally, the literature reviews in those chapters indicated a student who is better calibrated has less mathematics anxiety and a growth mindset student is more likely to have better mathematics achievement. Also, a growth mindset student is more likely to be less mathematically anxious and better calibrated while a less mathematically anxious student is more likely to be better calibrated.

Chang and Beilock (2016) suggested further investigations into factors that could explain the link between mathematics anxiety and achievement are needed. Herts and Beilock (2017) expanded upon this call by indicating more mathematics anxiety and achievement researchers need to focus on how mathematics anxiety influences the learning process as this has important, broader implications for teaching mathematics. Legg and Locker (2009) also suggested further research needs to be conducted to better understand the relationship between metacognition and mathematics anxiety.

Following suggestions from Chang and Beilock (2016), Herts and Beilock (2017), and Legg and Locker (2009) about investigating the relationship among these constructs, this dissertation examined the relationship among pre-service elementary teachers' mathematical mindset, calibration, mathematics anxiety, and achievement in two content courses by addressing the following research questions:

Q1 What is the statistical relationship between calibration and mindset for pre-service elementary teachers?

Q1a Is there a statistically significant difference in calibration over time for pre-service elementary teachers who demonstrate a fixed and those who demonstrate a growth mindset throughout the semester accounting for instructor and semester?

Q2 What is the statistical relationship between calibration and mathematics anxiety for pre-service elementary teachers?

Q2a Is the change in mathematics anxiety of underconfident pre-service elementary teachers statistically significantly different from the change in mathematics anxiety of overconfident teachers accounting for instructor?

Q3 What is the statistical relationship between calibration and mathematics achievement for pre-service elementary teachers?

Q3a Does calibration statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q4 What is the statistical relationship between mindset and mathematics anxiety for pre-service elementary teachers?

Q4a Is there a statistically significant difference in mindset between low, moderate and high math anxious pre-service elementary teachers at the beginning and end of the semester accounting for instructor and semester?

Q5 What is the statistical relationship between mindset and mathematics achievement for pre-service elementary teachers?

Q5a Is there a statistically significant difference in the change in mindset for students of different achievement levels accounting for instructor and semester?

Q6 What is the statistical relationship between mathematics anxiety and mathematics achievement for pre-service elementary teachers?

Q6a Does the change in mathematics anxiety statistically significantly differ between different levels of mathematics achievement for pre-service elementary teachers accounting for instructor?

Q7 Does calibration, mindset, and mathematics anxiety predict mathematics achievement for pre-service elementary teachers?

Q7a Does calibration and mathematics anxiety statistically significantly predict mathematics exam performance in pre-service elementary teachers accounting for instructors?

Q7b Does calibration and mathematics anxiety predict final exam performance accounting for instructor?

Q7c Does mindset, calibration and mathematics anxiety predict mathematics exam performance in pre-service elementary teachers accounting for semester and instructor?

To answer these research questions, three quantitative studies were conducted. These studies were conducted in mathematics content courses taught in the mathematics department at a four-year doctoral granting institution in the Rocky Mountain region. Content courses included in the studies were first and third mathematics content courses of a required three-course sequence for pre-service elementary teachers. In all three studies, calibration, mathematics anxiety, and demographic surveys were collected along with three exams. The second and third studies also collected final course grades while the third study included mindset surveys.

Recall that calibration is the alignment between what people think they can do on a task versus what they can actually do on the task. There are many ways to measure calibration (Alexander, 2013) but for this dissertation, calibration accuracy and bias were used along with examining accuracy and bias at the local and global levels. Calibration accuracy measures the degree to which a person's belief of ability (i.e., self-efficacy) to perform a task corresponds to his/her performance on that task while calibration bias indicates whether a student under- or overestimates his/her ability and by how much (Bol et al., 2012; Keren, 1991; Nietfeld et al., 2005; Zimmerman & Moylan, 2009). Global calibration examines calibration accuracy and bias at the level of the whole exam while the level for local calibration is each question on the exam.

Self-efficacy and self-evaluation surveys were used to measure prediction and postdiction calibration, respectively. Survey items that asked students to indicate how many points they would receive on each problem or part of a problem were used to calculate the local calibration. The last item on the surveys, which asked students to indicate how many points they would get on the entire exam, was used to calculate global calibration. To calculate local prediction calibration accuracy, the following formula was used:

$$Local\ Prediction\ Calibration\ Accuracy = \frac{\sum_{i=1}^{n} |self - efficacy\ score\ on\ question\ i - actual\ score\ on\ question\ i|}{total\ points\ for\ the\ test}$$

where *n* represents the total number of problems on the exam. To calculate local prediction calibration bias, the absolute value in the previous calculation was dropped.

To calculate global prediction calibration accuracy, the following formula was used:

$$Global\ Calibration\ Accuracy\ Score = \frac{|estimated\ prediction\ score\ on\ the\ exam - actual\ score\ on\ the\ exam|}{total\ points\ for\ the\ exam}.$$

Global prediction calibration bias was calculated by dropping the absolute value in the previous calculation. Global postdiction calibration accuracy and bias were calculated the same way as their prediction calibration counterparts except self-efficacy scores were replaced with self-evaluation scores in each formula.

The first study in Chapter II examined the influence of calibration and mathematics anxiety on exam performance for pre-service elementary teachers enrolled in the first mathematics content course during the 2015 fall semester. To better explore the relationship among calibration, mathematics anxiety, and achievement for pre-service elementary teachers, the second study in Chapter III had a different data collection method along with having participants from the first and third mathematics content courses for pre-service elementary teachers during the spring semester of 2017. The third study in Chapter IV was conducted to continue the exploration of the influence of calibration and mathematics anxiety on mathematics achievement but to also investigate the relationship among mindset and the constructs of calibration, mathematics anxiety, and achievement. This was accomplished using data collected from the first and third mathematics content course during the spring and fall semesters of 2017, which allowed me to investigate how the relationship was similar or different between students from different semesters. The first and third mathematics content courses appear in the pre-service elementary major program to be taken during the first-year and second-year fall semesters, respectively. Most of the students in the fall semesters of 2015 and 2017 were taking the courses when they should while the students in the spring semesters of 2017 were not. Given the schedule for students, the spring semester courses tended to have more students repeating the courses.

Summary and Discussion of Findings

The findings of the three studies were described in Chapters II, III, and IV. The purpose of this section is to synthesize the results and findings to answer the research questions outlined in Chapter I. Chapters II and III findings were synthesized to answer the questions relating to the relationship between calibration and mathematics anxiety and calibration and mathematics achievement while Chapter IV findings were utilized to answer the questions related to mindset.

Research Question 1

The first research question investigated the relationship between calibration and mindset for pre-service elementary teachers. This question was discussed in Chapter IV using mixed ANOVAs with the fixed effect of mindset level while also accounting for the role of instructor and semester. The results indicated content covered (i.e., specific exams such as the first, second, and final exams), level of mindset (i.e., strong growth-oriented, growth-oriented, and fixed-oriented), and the semester (i.e., fall or spring) might have influenced pre-service elementary teachers' calibration. For the second exam, growth mindset students were more confident in their global postdiction calibration than the fixed mindset students. For global prediction calibration accuracy, growth mindset students were more accurate than fixed mindset students during the spring semester while growth mindset students were more accurate in their global postdiction calibration than the fixed mindset students during the fall semester. Additionally, strong growth-oriented mindset students were significantly more accurate in their local prediction calibration and closer to being neither under- nor overconfident in their global prediction calibration than fixed mindset students. Overall, these results seemed to indicate the more growth mindset students were, the more calibrated they were. This finding corresponded to a theoretical relationship between mind and calibration as mentioned earlier. More details of the results and possible reasoning for this relationship are provided in Chapter IV.

Research Question 2

The second research question investigated the relationship between calibration and mathematics anxiety for pre-service elementary teachers. This question was investigated in studies discussed in Chapters II and III using correlational analysis and ANOVAs, respectively. For the correlation analysis, local prediction calibration accuracy was weakly, but significantly correlated with mathematics anxiety. Bias was also weakly correlated but not significantly. These results suggested that as students became more anxious, they became less calibrated. This finding fit within the metacognitive model (Nelson & Narens, 1990, 1994; Van Overschelde, 2008) where mathematics anxiety is a perceived constraint that can inhibit students' ability to calibrate. For the ANOVA, the fixed effects were average semester biases for local and global prediction and postdiction calibration bias while the change in mathematics anxiety was the dependent variable. Also, instructor was accounted for in the model. Throughout the semester, the underconfident students as determined by the average global prediction calibration bias had a significant decrease in mathematics anxiety while the overconfident students had a significant increase in their mathematics anxiety. This pattern also held for the average local prediction, local postdiction, and global postdiction calibration biases even though the differences were not significant. The ANOVA results seemed to indicate the underconfident students tended to have their mathematics anxiety decrease over the semester while overconfident students tended to have the opposite pattern. Overall, these results seemed to show mathematics anxiety and calibration had a significant relationship but the relationship type, cause-and-effect or circular, was unknown in the current analyses. As previously mentioned, mathematics anxiety can theoretically inhibit students' calibration. However, within the metacognition model, calibration could also influence mathematics anxiety as the over- and underconfidence students have on a problem could reduce or increase their mathematics anxiety, respectively. Additionally, mathematics anxiety and measures of confidence have been found to be inversely correlated (e.g., Jameson & Fusco, 2014; Legg & Locker, 2009; Malpass et al., 1999). More details of the results and possible reasoning for this relationship are provided in Chapters II and III.

Research Question 3

For the third research question, the relationship between calibration and mathematics achievement was examined in studies shared in Chapters II and III. In these studies, I utilized correlational analysis and linear mixed model analysis (Chapter II) and ANOVAs (Chapter III). For the correlational analysis, local prediction calibration was significantly correlated to exam performance at a moderate level. In particular, as students became better calibrated in terms of accuracy and more underconfident, their exam performance increased. This was further supported by the linear mixed model analysis, which showed local prediction calibration accuracy and bias were significant predictors of exam performance but the influence of bias depended on the course instructor. Mixed ANOVAs were utilized to investigate the effect of final grade performance on the change of calibration over time accounting for instructor. The ANOVA analysis indicated the teacher (i.e., which instructor), content covered (i.e., which exam), and the students' level of course achievement (i.e., the final course grade) could influence pre-service elementary teachers' calibration. Students' local calibration was influenced by teachers but the size of the influence depended on the course and exam content; in particular, lower achieving students were more influenced by teachers. Meanwhile, higher achieving students tended to be more globally calibrated. Overall, these results indicated higher achieving students were better calibrated but, more importantly, teachers played a key role in assisting students' calibration efforts. The relationship between calibration and mathematics achievement was similar to correlational analyses conducted by Chen and Zimmerman (2007) and Garcia et al. (2016). More details of the results and possible reasoning for this relationship are provided in Chapters II and III.

Research Question 4

The relationship between mindset and mathematics anxiety was examined for the fourth research question in the study discussed in Chapter IV. This study employed ANOVAs with fixed effects of mathematics anxiety level, instructor, and semester, and the dependent variable of mindset. At the beginning of the semester, low and moderate mathematics anxious students had a more growth mindset orientation than high mathematics anxious students. A similar finding was discovered at the end of the semester when comparing low and moderate mathematics anxious students to high mathematics anxious students. Also, low anxious students were more growth mindset oriented than the moderate anxious students but not at a significant level. This seemed to indicate lower mathematics anxious students possessed a more growth mindset. This finding fit within the metacognitive model and the influence mindset could have on mathematics anxiety. In particular, the more growth mindset students were, the more likely they were to use their mathematics as a motivator for their studying instead of using their mathematics anxiety as a demotivator. More details of the results and possible reasoning for this relationship are provided in Chapter IV.

Research Question 5

To investigate the fifth research question, the relationship between mindset and mathematics achievement was examined. This study (see Chapter IV) used ANOVAs with fixed effects of mathematics achievement level (i.e., final course grade), instructor, and semester, and the dependent variable of difference in mindset. Students who earned As and Bs for their final course grade had their mindset change to a more growth mindset orientation while students who earned a C, D, or F grade had their mindset become more fixed. Although the change for the A students was not as large as for the B students, this might have been due to the fact that the A students had a slightly more growth mindset at the beginning and end of the semester. This result indicated students who tended to do well in mathematics developed a more growth mindset while those who did not do well developed a more fixed mindset. This finding was similar to results from Aronson et al. (2002) and Good et al. (2003) wherein a more growth mindset corresponded to better mathematics performance. More details of the results and possible reasoning for this relationship are provided in Chapter IV.

Research Question 6

The sixth research question investigated the relationship between mathematics anxiety and achievement for pre-service elementary teachers. The correlational analysis and linear mixed model analysis utilized in Chapter II found a significant but weak relationship between mathematics anxiety and achievement, which indicated that as a student became more anxious, his/her exam performance decreased. The ANOVA utilized in Chapter III had the change in mathematics anxiety as the dependent variable and the fixed effects were final course grade and instructor. Similar to the relationship between mindset and mathematics achievement found in the fourth research question (see Chapter IV), students with a final course grade of A/B tended to reduce their mathematics anxiety throughout the semester while the C, D and F students tended to have their mathematics anxiety grow. Also, the higher the grade a student had, the more their mathematics anxiety decreased or the smaller the increase in mathematics anxiety. This finding indicated the higher performing students tended to have their mathematics anxiety change for the better. Overall, the results indicated previous performance might influence mathematics anxiety, which might in turn affect exam performance. Previous research has shown mathematics anxiety to negatively influence mathematics performance (e.g., Andrews & Brown, 2015; Cargnelutti et al., 2017) while also providing some indications of a cyclic relationship between mathematics anxiety and achievement (Gunderson et al., 2018). More details of the results and possible reasoning for this relationship are provided in Chapters II and III.

Research Question 7

To address the seventh research question, I share some of the results related to the possible influence of calibration, mindset, and mathematics anxiety on mathematics achievement. The linear mixed model analysis in Chapter II indicated local prediction calibration accuracy, local prediction calibration bias through an interaction with a teacher, and mathematics anxiety influenced exam performance. The multiple linear regression model in Chapter III also found local and global prediction calibration accuracy and bias, and mathematics anxiety influenced final exam performance with interaction between global prediction calibration bias and mathematics anxiety and mathematics anxiety and teachers. The multiple linear regression in Chapter IV found similar results to the Chapter III regression along with mindset being a significant predictor of final exam performance except the interaction effects were between local and global prediction calibration accuracy and teachers, local calibration bias and semester, global calibration bias and local calibration bias, global calibration bias and mathematics anxiety, mathematics anxiety and teachers, and mindset and teachers. The results indicated calibration, mindset, and mathematics anxiety were significant predictors of exam performance. Additionally, teachers played a key role in students' development of mindset, calibration, and mathematics anxiety. There seemed to be a significant relationship between calibration and mathematics anxiety that affected mathematics performance. This result further supported findings for the second research question in which lower mathematics anxiety corresponded to better calibration. Lastly, students' calibration might depend on when (spring or fall) they took the course and/or whether they were retaking the course. The results matched the literature for calibration (e.g., Chen, 2003; Freeman et al., 2017), mindset (Claro et al., 2016; McCutchen et al., 2016), and mathematics anxiety for pre-service teachers (e.g., Hembree, 1990; Novak & Tassell, 2017) being predictors of mathematics performance. As previously mentioned, mathematics anxiety can theoretically inhibit students' calibration or vice versa within Nelson and Narens's (1990, 1994) metacognition model. More details of the results and possible reasoning for this relationship are provided in Chapters II, III, and IV.

Implications

Teaching

The result of this study showed the teacher as a fixed variable influenced local prediction calibration bias, global prediction calibration accuracy, mathematics anxiety, and mindset. As each teacher has different teaching styles and preferences of what to emphasize, this result seemed reasonable. This result implied various teaching techniques and in-class interactions teachers have with students could reinforce such growth in these areas. As no in-class observation data were collected in this study, this particular implication could be explored further.

Additionally, given the interactions among teacher and calibration, mindset, and mathematics anxiety in the analyses, instructors of these students play a key part in their calibration, mindset, mathematics anxiety, and consequently, mathematics achievement. As we know mathematics anxiety can transfer from teachers to students from research conducted by Beilock et al. (2010), Gunderson et al. (2012), and Jackson and Leffingwell (1999), this dissertation also indicated teachers' instructional methods and actions impacted more than mathematics anxiety. Teachers should be aware of their students' calibration, mindset, and mathematics anxiety. By being aware of such things, teachers can make appropriate actions in their instruction. For example, during review for exams, teachers could have students read a review problem and, before solving the problem, have students think about if it was an exam problem what they would need to know to solve the problem and how well they would do on the problem. Then the students could solve the problem and check to see how calibrated they were by comparing their performance on the problem to their initial estimate. A few other methods might help students' learning through improvement in calibration, mindset, and mathematics anxiety.

As mentioned in Chapters III and IV, metacognition training, which includes metacognitive skills necessary for calibration, would improve students' mathematics achievement as long as the training was integrated into the mathematical content (Bol et al., 2012; Cardelle-Elawar, 1995; Kramarski & Dudai, 2009; Kramarski & Mevarech, 2003; Kruger & Dunning, 1999). The influence of metacognitive training on students' ability to calibrate was found by Bol et al. (2012) in which students who utilized their metacognitive guidelines in groups displayed the greatest global calibration accuracy with the individual metacognitive guidelines displaying the second greatest global calibration accuracy compared to group setting and individual setting with no metacognitive guidelines. Additionally, Bol et al. (2012), Kramarski and Mevarech (2003), and Kramarski and Dudai (2009) found metacognitive training and group work combined delivered the best environment for improving student performance. As teaching practices continue to shift from teacher-centered to student-centered, students' metacognitive monitoring and control of their learning are becoming more important for their learning and success (Kostons & de Koning, 2017).

Considering the relationship among mindset, calibration, and mathematics anxiety, and their impact on mathematics achievement, teaching techniques to promote growth mindset discussed by Dweck (2006) and Boaler (2016) might assist students in becoming better calibrated and less mathematics anxious. However, there is a note of caution when it comes to praising just students' efforts. As Dweck (2015) mentioned, students' efforts need to work in conjunction with new and existing strategies and input from others when stuck. Strategies for problem solving could can assist students' efforts are learning from mistakes and reflecting on previous failed strategies to determine what was useful and not useful, and if possible, why. Praising students' efforts without these two things does not lead to learning and might only momentarily make them feel good.

These teaching implications are not only important for students in general but also important for pre-service mathematics teachers as they will eventually teach and assist students in developing skills and motivations that go beyond knowing mathematics. These other skills and motivations could include calibration, mindset, and mathematics anxiety. By allowing pre-service teachers to go through the experience of becoming better calibrated, lowering their mathematics anxiety, and developing a growth mindset in a mathematics class, they can bring these teaching methods into their own classroom and assist future generations of students to become more proficient self-learners who accept the challenges that come with learning mathematics instead of avoiding mathematics and STEM careers. These teaching implications for pre-service elementary teachers' mathematics anxiety are what Chang and Beilock (2016), Herts and Beilock (2017), and Ramirez et al. (2018) called for as mathematics anxiety can influence mathematics achievement through learning processes related to mindset and calibration.

Research

Given the study, three implications for research are related to the surveys given to participants to complete. First, the mathematics anxiety and mindset surveys conducted at the end of the semester were given the week before the final exams as mentioned in Chapters II, III, and IV. Because these measurements were used in the regression models in those chapters, the influence of mathematics anxiety and mindset on final exam performance might not have been as strong as it could have been. This was unavoidable as the instructors were concerned that the mathematics surveys given right before the exam would affect students' performance. Also, there was a concern that too much time would be taken away from the exams if three surveys (mindset, mathematics anxiety, and self-efficacy) were given right before each exam. In the future, I will determine a way to measure mathematics anxiety closer to an exam time while also avoiding the negative influence of students thinking of their mathematics anxiety before an exam.

Second, self-efficacy and self-evaluation surveys need to be improved. There were several occasions in the data when students did not provide point estimates on the surveys or provided point estimates not possible such as obtaining 10 points on a problem worth eight points. This might have been due to students not realizing they missed filling in a blank or mixed up the point values for one problem with another problem. This caused students data to be missing when calculating local calibration accuracy and bias. Also, considering that a majority of students added their item-by-item scores on the surveys to get their estimate for the entire exam, this might mean some of the global calibration accuracy and bias scores might not represent students' actual calibration. Next time I collect data using self-efficacy and self-evaluation surveys, each half page or full page will have a problem and a place for students to insert their point estimate for the problem.

Third, the self-efficacy and self-evaluation surveys used a different scale than Hacker et al. (2008b) and other researchers (e.g., Chen, 2003; Ozsoy, 2012) used. The scales these researchers used were confidence judgment using a 10-point or 100-point scale or confidence line as suggested by Hacker et al. (2008b). However, in this dissertation, students used point values to determine their calibration scores as most exam questions were open-ended with a few multiple choice or matching problems. Open-ended questions made it hard to determine what a certain level of confidence meant in terms of point values. Thus, students were asked to take an additional step and use their confidence and knowledge of their instructor to determine how many points they would get per problem or part of a problem as this was more aligned with their current thoughts when it came to success on an exam. Even though this did not follow standard convention described by Hacker et al. (2008b) for calculating calibration accuracy and bias, Alexander (2013) mentioned there is no standard way to collect calibration judgments and calculate calibration. Also, Bol et al. (2012) used point values when determining global calibration accuracy. More studies utilizing point values for calculating calibration need to be analyzed to see if the results corresponded to calibration calculated using confidence judgments but also to investigate the influence of an additional layer of accounting for teacher grading methods.

Policy

There are a couple of implications for policy in these studies. Students understanding mathematical content is important matter but it is not enough. This is particularly important for pre-service teacher population as Ball et al. (2008) and Hill et al. (2005) stated learning mathematics content is not enough for pre-service teachers. Students need metacognitive training that includes calibration as part of their learning of mathematics. This would allow students to better analyze their own thoughts and improve their strategy use, which besides improving their mathematics achievement better prepares them to be self-learners.

The Mathematical Association of America's 2015 *CUPM Guide to Majors in the Mathematical Sciences* discussed not only cognitive goals but also metacognitive habit of mind goals mathematics majors should develop to increase their understanding and learning of mathematics (Zorn, 2015). These habits of mind are not only important for understanding and learning mathematics but are also important for students to be life-long learners of mathematics by providing students with skills necessary for them to continually develop their thinking and understanding of the world. Similarly, Conference Board of the Mathematical Sciences (2012) reported on recommendations for mathematics teachers should know and how they should learn mathematics. They mentioned that teachers need to have mathematical habits of mind in order to monitor their mathematical thinking and language during problem solving and, more importantly, assist their students in developing mathematical habits of mind. Consequently, pre-service teacher courses should be taught in ways that allow these habits to develop for pre-service teachers. More policy documents similar to the MAA's *Guide to Majors in the Mathematical Sciences* and Conference Board of the Mathematical Sciences' (2012) recommendations are needed on habits of mind of pre-service elementary teachers and how to assist students in developing them in elementary school.

Another implication is growth mindset instruction needs to be incorporated into standards for teaching as well as the standards for mathematics curricula. Growth mindset has been shown to cause students to be more willing to work on challenging problems through purposeful effort that improved mathematics resilience and achievement. However, the studies in this dissertation provided indications that the link between mindset and mathematics achievement might be mediated by constructs such as mathematics anxiety and calibration. In particular, students' mindset might influence their calibration and mathematics anxiety during test taking, which has become increasingly important today as assessment plays an important role in decisions made in standards and education at Pre-K-12 levels. Growth mindset students have more of a tendency to use their mathematics anxiety as a motivator to solve problems and their metacognition in a more purposeful manner when putting in the effort to solve those problems than fixed mindset students.

However, one needs to be careful about how to develop growth mindset for students in underrepresented groups. Dr. Luke Wood (cited in Hilton, 2017) discussed that growth mindset is an incomplete idea that does not account for underrepresented groups in the broadcast of Black Minds Matter. From Wood's work with African American males in education who have rarely heard praise of their ability, which has been shown to be a significant predictor of their mathematical success and performance, he suggests the dichotomy between praising ability and effort needs to be erased; instead, students' efforts and ability should be praised together. This showed how decisions and policy are developed heavily on assessments such as SAT and ACT, which have a large portion of students being Caucasian, and results in policies and rules that do not work for underrepresented groups. Additionally, these assessments measure students' ability, which mindset practices downplay. Growth mindset practices should align to incorporate not only effort but ability in order to better assist students of diverse background succeed in the U.S. education system.

Limitations

Besides the limitations mentioned in Chapters II, III, and IV, several other limitations were related to data collection. First, when collecting data throughout the semester, several classes had overlapping meeting times. Consequently, I had to collect data at either different times during the class meeting (i.e., beginning, middle, or end of class), a different day, or had someone else (approved by the IRB) collect data for me during the spring and fall of 2017. When collecting the mindset and mathematics anxiety data at the beginning and end of the semester, I had to arrange to go to the classes at different times during the same or a different class day. This meant some students' mindset and mathematics anxiety at the beginning of the semester were not necessarily what the students entered the class with, especially the classes I obtained data from on the second day of class of the semester as they had time to get a better idea of the instructor and course. These interactions on the very first day of the semester might have adjusted students' mindset and mathematics anxiety. At the end of the semester, some instructors had me attend their class two class days before the final exam while another had me attend the class day before. Those classes surveyed the class day before the final exam might have had their mindset and mathematics anxiety measurements closer to what their measurements would have been if the surveys were given right before the final exam. These differences in measurement times might have changed some of the results related to the connection among mindset, mathematics anxiety, and achievement.

Besides this difference in data collection between several classes, I had a few people help me collect the self-efficacy and self-evaluation surveys because several classes with the same meeting time gave a test the same day and self-efficacy surveys needed to be given right before the exam. While this might not have caused any difference between students' responses for most of the classes with which I had help, there is evidence that one person might have caused some participant bias. Teacher X collected the self-efficacy and self-evaluation surveys for me from his/her students. The students in Teacher X's class tended to be the most uncalibrated of all the classes. Even though Teacher X followed the script approved by the IRB to state he/she would not see the data collected, this might have resulted in students not wanting their instructor to think they thought they were not smart and, as a result, overestimated their ability on the surveys. Subsequently, the difference in calibration between Teacher X and the other teachers led to the teacher being a significant factor in several statistical tests. Even accounting for this, teachers seemed to be a key factor in the relationship among mindset, calibration, mathematics anxiety, and achievement but might not be as big of a factor if the students of Teacher X had their data collected by someone else.

For determining the total points for each exam for the self-efficacy and self-evaluation surveys, students were told to estimate how well they would do on the exam similar to how they estimated their performance on each problem on the exam. However, from my observation of students filling out the surveys, most students instead just summed their estimates for each problem to get their overall exam performance estimate. As a result, participants did not go through the same or similar metacognitive processes they went through for the item-by-item point estimates. This might mean the relationship among global calibration, mindset, mathematics anxiety, and achievement may not have been the true relationship among these constructs.

Another limitation of the study was class observations were not utilized. Without class observations, there was no empirical evidence of how teaching methods utilized in the pre-service elementary teachers' mathematics content courses influenced students' calibration, mindset, mathematics anxiety, and achievement. Such data would provide insight into the effect of teachers on calibration, mindset, mathematics anxiety, and achievement.

Future Research

From the results and limitations of the dissertation, I provide several ideas for future research. The last limitation needs to be addressed in future research as teachers seemed to be important for students' calibration, mindset, mathematics anxiety, and achievement. This could be accomplished using a mixed-methods study with the surveys used in the dissertation and ethnographic observations. The surveys could be given similar to the Chapter IV study while researchers observed the teachers and the methods they utilized with students to see if there were any relationship between the teaching techniques and changes in the survey measurements.

The second to last limitation on collecting global calibration needs to be addressed by conducting research that examines the relationship among global calibration, mindset, mathematics anxiety, and achievement without asking participants to estimate their item-by-item performance. This would make participants use their metacognitive processes to formulate their estimates. To research this, similar methods and analysis utilized in Chapters III and IV could be conducted to compare the results of the study to the results in the dissertation. In particular, the participants would read over the entire exam and then make their judgements similar to Bol et al. (2012).

Another research idea builds off research conducted for the dissertation. In particular, the research in the dissertation showed calibration, mindset, mathematics anxiety, and achievement were related to each other but exactly how they were related was not exactly clear. Some research indicated mathematics anxiety might mediate the relationship between calibration and mathematics achievement (Chen, 2003; Malpass et al., 1999; Meece et al., 1990; Pajares, 1996; Pajares & Kranzler, 1995). However, based on the metacognitive model and the results of this dissertation, mindset seemed to be a factor that influenced the other constructs while calibration seemed to be a mediating factor between achievement and the other two constructs – mindset and mathematics anxiety. Also, there is a possibility the relationship between the constructs was circular in the sense previous mathematics achievement influenced mindset and the remaining constructs. This could be investigated through a path analysis or a structural equation model could be developed by collecting calibration, mindset, mathematics anxiety, and achievement data for an exam.

A future research study could explore one of the results of Chapter IV about the mindset of pre-service elementary teachers. At the beginning and end of the semester, most pre-service elementary teachers (90.03% female) indicated they were more growth mindset oriented. This contradicted Boaler’s (2014) results that females tend to have a high level of fixed mindset in mathematics courses. The idea of false growth mindset in educators (Dweck, 2015) might be a concern as pre-service elementary teachers might then develop a false growth mindset. People who have a false growth mindset claim they have a growth mindset while their actions and language indicate otherwise. I am wondering if this was the case with students in Chapter IV in the sense that as prospective educators they might have heard of growth and fixed mindsets; to avoid looking like they do not support the growth of intelligence, they might have indicated on the survey they were on the growth side of mindset while they actually were not. As mathematics education researchers, we need to explore this further so we can take appropriate actions in class to stop the development of false growth mindset and start the development of an actual growth mindset. Furthermore, by being careful with catch phrases and their uses, we can avoid the development of incorrect ideas that would hinder teachers' instruction methods and students' development of mathematical knowledge and learning.

This is especially important for pre-service teachers as mathematical mindset held by teachers tends to influence students' mindset to become similar to their teachers (Boaler, 2016; Dweck, 2006; Leslie et al., 2015). To investigate if pre-service teachers have or are developing a false growth mindset, a mixed methods study might be required where students are surveyed for their mindset but also observed throughout the semester and possibly interviewed to see if their actions and language matched the survey results. Interviews could explore their study habits or give students scenarios that could be used to investigate their growth mindset.

The last future research suggestion came from the population utilized in this dissertation. Pre-service elementary teachers were examined mainly due to the influence they have on elementary students as they are one of the first people to introduce mathematics formally to students and could have a big influence on their students' pursuit of STEM fields. However, other populations of undergraduates are important to examine for calibration, mindset, mathematics anxiety, and achievement. In particular, undergraduates who take college algebra and calculus are important populations to examine as these two courses are gateways to obtaining a degree (Adelman, 2006). Foley et al. (2017) mentioned mathematics anxiety should be considered when attempting to improve STEM career success. Additionally, as indicated in this dissertation, calibration and mindset seemed to influence mathematics achievement, which in turn could influence students' career choices. Bressoud, Mesa, and Rasmussen (2015) recommended mindset be considered to promote higher-order thinking in Calculus I. Also, the *MAA Conference on Precalculus to Calculus: Insights & Innovations* (Bressoud, 2016) mentioned growth mindset needs to be developed in calculus courses using discussions, in-class and out-of-class activities, and readings and reflections about growth mindset. Given the increased importance of growth mindset in Calculus I and similar importance of mindset for college algebra, these two populations could be studied similar to how the studies in the dissertation were conducted to examine how the constructs related to each other in these populations. Then further research could be conducted to develop teaching techniques that promote a growth mindset, lower mathematics anxiety, and assist students become better calibrated to improve mathematics achievement.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL FOR FIRST STUDY

UNIVERSITY of NORTHERN COLORADO

Institutional Review Board

DATE:	September 10, 2015
TO:	Brian Christopher
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[796676-2] The Relationship between Calibration, Achievement and Anxiety for Preservice Elementary Teachers in Mathematics
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	September 9, 2015
EXPIRATION DATE:	September 9, 2019
REVIEW TYPE:	Exempt Review

Thank you for your submission of Amendment/Modification materials for this project. The University of Northern Colorado (UNCO) IRB has APPROVED your submission. All research must be conducted in accordance with this approved submission.

This submission has received Exempt Review based on applicable federal regulations.

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

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

All UNANTICIPATED PROBLEMS involving risks to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of September 9, 2019.

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

If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Northern Colorado (UNCO) IRB's records.

APPENDIX B

INFORMED CONSENT FORM FOR FIRST STUDY

UNIVERSITY of NORTHERN COLORADO

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title: The Relationship between Calibration, Achievement and Anxiety for Pre-service Elementary Teachers in Mathematics
Researcher: Brian Christopher, School of Mathematical Sciences, brian.christopher@unco.edu,
970-351-2229
Research Supervisor: Dr. Gulden Karakok, gulden.karakok@unco.edu, 970-351-2215

To better understand undergraduate students' mathematics abilities, I am researching the relationship between calibration, achievement and anxiety in the mathematics classroom for pre-service elementary teachers. I am writing to ask you to participate in this study. If you agree to participate, then participation will entail taking a brief anxiety survey after signing this form and near the end of the semester. Also, you will be asked to take a short survey before each test. The anxiety survey will take at most 10 minutes and the other surveys will take at most 5 minutes each. The surveys before each test will ask you to estimate how many points you think you will get on the test for each problem without actually doing the problem. Your instructor will not be in the class when the surveys are being administered so that they will not know if you are participating. Besides collecting the surveys, I will be collecting a copy of your graded tests if you agree to be in the study. Tests are a normal part of the class and you will be required to take them even if you are not part of the study. During the tests, I will not be in the classroom. The surveys and assessment will help me determine possible influences of calibration, achievement and anxiety on each other. Regardless of participating or not, everyone will get the same amount of time on the assessment. **In order to be eligible to participate, you must be at least 18 years old.**

By being in this study or declining to be in the study, your classroom standing and any benefits or rights you are entitled to will not be impacted. If you agree to participate in this study, you may choose to stop participating at any time. I do not see any potential risk of participation other then what is normally encountered in a classroom. You will not be compensated for participating in this study nor will you be penalized in any way for not participating in this study. During the study, I will be happy to share your research results with you at your request.

I will take every precaution in order to protect your confidentiality. To maximize confidentiality, any data obtained will be immediately coded using an alphanumeric coding and then your name on the paper will be blacked out. All original data will be kept in a locked file cabinet in my office at the University of Northern Colorado and will be destroyed after three years. Any electronic copies of the data will be stored on a password-protected computer in my office at the University of Northern Colorado. The only people who will have access to the data are my research advisor and me. Please feel free to contact me using the addresses above or my research advisor, Dr. Gulden Karakok.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

____
Participant Name (please print your name)

______________________________________ ____________________
Participant Signature Date
(month/day/year)

______________________________________ ____________________
Researcher's Signature Date
(month/day/year)

______________________________________ ____________________
Researcher Supervisor Signature Date
(month/day/year)

APPENDIX C

MATHEMATICS ANXIETY SURVEY FOR FIRST STUDY

Students' Mathematics Anxiety Survey

For each of the following statements, please circle the one response that best fits your view.

1) **It wouldn't bother me at all to take more mathematics courses.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

2) **I have usually been at ease during mathematics tests.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

3) **I have usually been at ease during mathematics courses.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

4) **I usually don't worry about my ability to solve mathematics problems.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

5) **I almost never get uptight when taking mathematics tests.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

6) **I get really uptight during mathematics tests.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

7) **I get a sinking feeling when I think of trying hard mathematics problems**

   Strongly Agree   Agree   Disagree   Strongly Disagree

8) **My mind goes blank when I think of trying hard mathematics problems.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

9) **Mathematics makes me feel uncomfortable and nervous.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

10) **Mathematics makes me feel uneasy and confused.**

   Strongly Agree   Agree   Disagree   Strongly Disagree

Please indicate the following information:

1) **Gender:** Male Female

2) **Year:** Freshman Sophomore Junior Senior Other

3) **Time Taking the Course:** First Time Second Time Third Time

4) **Concentration Area (Circle any that apply. If your area is not listed, feel free to write it in below the 20 choices.):**

1. Biology	2. Chemistry	3. Civics (Political Science)	4. Creative Drama	5. Earth Science
6. Environmental Studies	7. ESL	8. French	9. Geography	10. German
11. History	12. Language Arts	13. Mathematics	14. Multicultural Studies	15. Music (Music Education Emphasis)
16. Music (Performance Emphasis)	17. Physics	18. Spanish	19. Visual Arts (Arts Integration Emphasis)	20. Visual Arts (Studio Emphasis)

I appreciate your time and collaboration. Thank you!

APPENDIX D

EXAMPLE OF MATHEMATICS EXAM

Mathematics TEST 1 – Fall, 2015

NAME:____

PART A - Read each question carefully, and show work that supports your answer. Be sure to provide illustrations where applicable. This exam is worth 100 points.

(1) (5 points) *Matching*. For each of the numbers below, choose the letter of the representation that COULD best represent that number. One letter will be used twice.

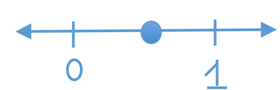
______ $(3 \times 1) + \left(1 \times \frac{1}{10}\right) + \left(4 \times \frac{1}{100}\right)$

______ 31.4

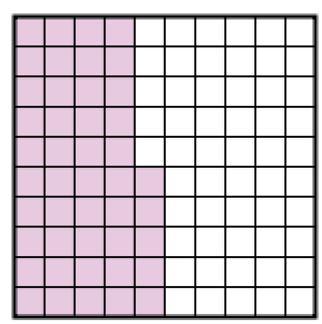
______ 314_6

______ Four thirds

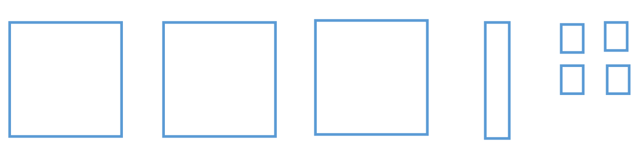
______ Forty-five percent

______ 

A. $\frac{11}{20}$

E. 

D. $(3 \times 10) + (1 \times 1) + \left(4 \times \frac{1}{10}\right)$

C. 

(2) (6 points)

(a) The image below represents $\frac{3}{4}$. Show one whole.

(3) (8 points) Find a fraction (with whole number numerator and denominator) between $\frac{7}{11}$ and $\frac{8}{11}$ by using equivalent fractions.

(4) (10 points) Use an illustration or a percent table to answer the following question: If a $\frac{4}{5}$ cup serving of yogurt provides your full daily value of calcium, then what percentage of your daily value of calcium is provided by $\frac{3}{5}$ cup of the yogurt?

(5) (9 points) Sally wants to make gluten-free cookies. The recipe calls for 7/8 cup of rice flour, but Sally only has $\frac{3}{4}$ cup of flour at home and no time to go to the store. Assuming she wants to keep all the ingredient ratios the same as in the recipe, what fraction of the recipe can she make? Show your work.

(6) (7 points) *Whole Numbers in Bases*.

What is 137_{10} in Base 5 (or in Quintopian numbers)? Use base blocks to illustrate your process OR use a computational method. Either way, show all of your work.

(7) (10 points) Geraldo wrote down a number in base 4 and Amy wrote down a number in base 2 and they asked Maria which one represents a larger number. Maria couldn't read the digit marked '?' in the numbers, but she still could say which number is bigger.

Geraldo's number:	Amy's number:
10?3$_4$	**10?101$_2$.**

(a) Explain how Maria could decide which number is larger without knowing either missing number. (Recall that the missing numbers are *digits*.) Make sure that your answer makes it clear whose number is larger.

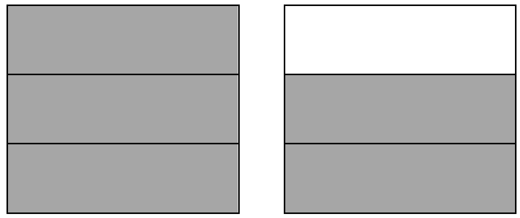
(b) If Geraldo's number is 75 in base 10, what is its missing digit?

Part B: Provide complete sentences that explain your reasoning. Also give illustrations where applicable.

(8) (7 points each) Solve the following subtraction and addition problems. Carefully **EXPLAIN** any "regrouping" or "trading in". Refer to base blocks pictures in your explanation as needed.

$$\begin{array}{r} 63_7 \\ +26_7 \\ \hline \end{array} \qquad \begin{array}{r} 61_8 \\ -43_8 \\ \hline \end{array}$$

(9) (6 points) (a) Mira says that the shaded region below represents the fraction $^5/_3$. Carmina says the shaded region represents the fraction $^5/_6$. **EXPLAIN** why each of the two student's answers can be considered correct.



(b) (6 points) Hannah says that $\frac{5}{6} = \frac{6}{7}$ because both fractions are one part away from a whole. Is Haley correct? **EXPLAIN** (without referring to finding common denominators).

(10) (10 points) You make $400 a week. You receive a 20% raise (salary increase) for your outstanding performance. Two months later, you get a 20% pay cut when the company is sold. What is your new salary? **EXPLAIN** your solution.

(11) (10 points) Solve the following problem using a strip diagram model. Lincoln has 4 more crayons than Milla. Lincoln has 14 crayons. How many crayons does Milla have? **Explain your diagram.**

APPENDIX E

SELF-EFFICACY SURVEY FOR FIRST STUDY

Directions: **DO NOT ATTEMPT the following problems**. Indicate how well you think you will do on each problem based on the number of points for each problem by filling in the blank in the sentence that follows each problem.

Name (Print): ___________________________

PART A - Read each question carefully, and show work that supports your answer. Be sure to provide illustrations where applicable. This exam is worth 100 points.

(2) (5 points) *Matching*. For each of the numbers below, choose the letter of the representation that COULD best represent that number. One letter will be used twice.

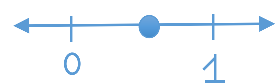
______ $(3 \times 1) + \left(1 \times \frac{1}{10}\right) + \left(4 \times \frac{1}{100}\right)$

______ 31.4

______ 314_6

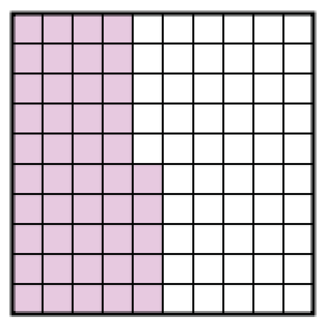
______ Four thirds

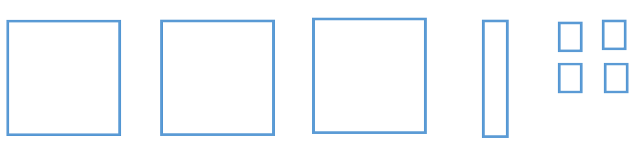
______ Forty-five percent

______ 

A. $\frac{11}{20}$

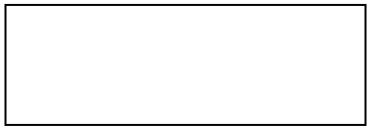
D. $(3 \times 10) + (1 \times 1) + \left(4 \times \frac{1}{10}\right)$

E. 

C. 

I will receive ____ points on this problem.

(2) (6 points)
(a) The image below represents $\frac{3}{4}$. Show one whole.



I will receive ____ points on this problem.

(3) (8 points) Find a fraction (with whole number numerator and denominator) between $\frac{7}{11}$ and $\frac{8}{11}$ by using equivalent fractions.

I will receive ____ points on this problem.

(4) (10 points) Use an illustration or a percent table to answer the following question: If a $\frac{4}{5}$ cup serving of yogurt provides your full daily value of calcium, then what percentage of your daily value of calcium is provided by $\frac{3}{5}$ cup of the yogurt?

I will receive ____ points on this problem.

(5) (9 points) Sally wants to make gluten-free cookies. The recipe calls for 7/8 cup of rice flour, but Sally only has $\frac{3}{4}$ cup of flour at home and no time to go to the store. Assuming she wants to keep all the ingredient ratios the same as in the recipe, what fraction of the recipe can she make? Show your work.

I will receive ____ points on this problem.

(6) (7 points) *Whole Numbers in Bases*.

What is 137_{10} in Base 5 (or in Quintopian numbers)? Use base blocks to illustrate your process OR use a computational method. Either way, show all of your work.

I will receive ____ points on this problem.

(7) (10 points) Geraldo wrote down a number in base 4 and Amy wrote down a number in base 2 and they asked Maria which one represents a larger number. Maria couldn't read the digit marked '?' in the numbers, but she still could say which number is bigger.

Geraldo's number:	**Amy's number:**
$10?3_4$	**$10?101_2$.**

(c) Explain how Maria could decide which number is larger without knowing either missing number. (Recall that the missing numbers are *digits*.) Make sure that your answer makes it clear whose number is larger.

(d) If Geraldo's number is 75 in base 10, what is its missing digit?

I will receive ____ points on this problem.

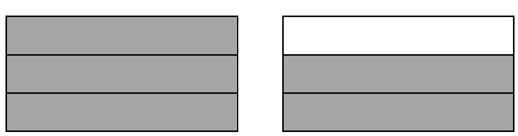
Part B: Provide complete sentences that explain your reasoning. Also give illustrations where applicable.

(8) (7 points each) Solve the following subtraction and addition problems. Carefully **EXPLAIN** any "regrouping" or "trading in". Refer to base blocks pictures in your explanation as needed.

$$\begin{array}{r} 63_7 \\ +26_7 \\ \hline \end{array} \qquad\qquad \begin{array}{r} 61_8 \\ -43_8 \\ \hline \end{array}$$

I will receive ____ points on this problem.

(9) (6 points) (a) Mira says that the shaded region below represents the fraction $^5/_3$. Carmina says the shaded region represents the fraction $^5/_6$. **EXPLAIN** why each of the two student's answers can be considered correct.



(b) (6 points) Hannah says that $\frac{5}{6} = \frac{6}{7}$ because both fractions are one part away from a whole. Is Haley correct? **EXPLAIN** (without referring to finding common denominators).

I will receive ____ points on this problem.

(10) (10 points) You make $400 a week. You receive a 20% raise (salary increase) for your outstanding performance. Two months later, you get a 20% pay cut when the company is sold. What is your new salary? **EXPLAIN** your solution.

I will receive ____ points on this problem.

(11) (10 points) Solve the following problem using a strip diagram model. Lincoln has 4 more crayons than Milla. Lincoln has 14 crayons. How many crayons does Milla have? **Explain your diagram.**

I will receive ____ points on this problem.

APPENDIX F

INSTITUTIONAL REVIEW BOARD FOR SECOND AND THIRD STUDY

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

DATE:	December 11, 2016
TO:	Brian Christopher
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[992982-1] The Relationship between Calibration, Mindset, Math Anxiety and Achievement for Preservice Elementary Teachers in Mathematics
SUBMISSION TYPE:	New Project
ACTION:	APPROVAL/VERIFICATION OF EXEMPT STATUS
DECISION DATE:	December 11, 2016
EXPIRATION DATE:	December 11, 2020

Thank you for your submission of New Project materials for this project. The University of Northern Colorado (UNCO) IRB approves this project and verifies its status as EXEMPT according to federal IRB regulations.

Brian -

Thank you for your patience with the UNC IRB process. Your application is exceptionally thorough and all materials are clear. Your materials and protocols are verified/approved exempt and you may begin participant recruitment and data collection after one small amendment is made to the consent forms. Please update the last sentence of the last paragraph verbatim as follows, "*If you have any concerns about your selection or treatment as a research participant, please contact Sherry May, IRB Administrator, in the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1910.*"

This change doesn't need to be submitted for subsequent review. Best wishes with your dissertation research. Don't hesitate to contact me with any IRB-related questions or concerns.

Sincerely,

Dr. Megan Stellino, UNC IRB Co-Chair

We will retain a copy of this correspondence within our records for a duration of 4 years.

If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Northern Colorado (UNCO) IRB's records.

APPENDIX G

INFORMED CONSENT FORM FOR SECOND AND THIRD STUDY

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title: The Relationship between Calibration, Mindset, Math Anxiety and Achievement for Pre-service Elementary Teachers in Mathematics
Researcher: Brian Christopher, School of Mathematical Sciences, brian.christopher@unco.edu,
970-351-2344
Research Supervisor: Dr. Gulden Karakok, gulden.karakok@unco.edu, 970-351-2215

To better understand undergraduate students' mathematics abilities, I am researching the relationship between calibration, mindset, math anxiety and achievement in the mathematics classroom for pre-service elementary teachers. I am writing to ask you to participate in this study. If you agree to participate, then participation will entail taking a couple of brief demographic, mindset and math anxiety surveys after signing this form and near the end of the semester. Also, you will be asked to take a short survey before and after each test. The mindset and math anxiety surveys will take at most 10 minutes and the other surveys will take at most 5 minutes each. The surveys before and after each test will ask you to estimate how many points you think you will get on the test for each problem without actually doing the problem. Your instructor will not be in the class when the surveys are being administered so that they will not know if you are participating. Besides collecting the surveys, I will be collecting a copy of your graded tests and your final course grade if you agree to be in the study. During the tests, I will not be in the classroom. The surveys and assessments will help me determine possible influences of calibration, mindset, math anxiety and achievement on each other. Regardless of participating or not, everyone will get the same amount of time on the assessment. **In order to be eligible to participate, you must be at least 18 years old.**

By being in this study or declining to be in the study, your classroom standing and any benefits or rights you are entitled to will not be impacted. If you agree to participate in this study, you may choose to stop participating at any time. I do not see any potential risk of participation. You will not be compensated for participating in this study nor will you be penalized in any way for not participating in this study. During the study, I will be happy to share your research results with you at your request.

I will take every precaution in order to protect your confidentiality. To maximize confidentiality, any data obtained will be immediately coded using an alphanumeric coding and then your name on the paper will be blacked out. All original data will be kept in a locked file cabinet in my office at the University of Northern Colorado and will be destroyed after three years. Any electronic copies of the data will be stored on a password-protected computer in my office at the University of Northern Colorado. The only people who will have access to the data are my research advisor and me. Please feel free to contact me using the addresses above or my research advisor, Dr. Gulden Karakok.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

____
Participant Name (please print your name)

____________________________________ __________________
Participant Signature Date
(month/day/year)

____________________________________ __________________
Researcher’s Signature Date
(month/day/year)

____________________________________ __________________
Researcher Supervisor Signature Date
(month/day/year)

APPENDIX H

DEMOGRAPHICS SURVEY FOR SECOND AND THIRD STUDY

Demographics Survey **Name:** ___________________

Please indicate the following information:

1) **Gender:** Male Female

2) **Ethnicity:**

3) **Year:** Freshman Sophomore Junior Senior Other

4) **Age:**

5) **First Generation College Student (You are a first generation student if your parents did not attend college.):** Yes No

6) **Did you transfer to the university from another university or community college?** Yes No

7) **If you transferred to this university, did you take any of the mathematics content courses at your old university? If yes, then indicate what courses you took.**

8) **Time Taking the Course:** First Time Second Time Third Time

9) **Major:**

10) **If your major is elementary education, please indicate concentration area (Circle any that apply. If your area is not listed, feel free to write it in below the 20 choices.):**

1. Biology	2. Chemistry/ Biochemistry	3. Civics (Political Science)	4. Creative Drama	5. ESL
6. Earth Science	7. Environmental Studies	8. French	9. Geography	10. German
11. History	12. Language Arts	13. Mathematics	14. Multicultural Studies	15. Music (Music Education Emphasis)

16. Music (Performance Emphasis)	17. Physics	18. Spanish	19. Visual Arts (Arts Integration Emphasis)	20. Visual Arts (Studio Emphasis)

OTHER:

APPENDIX I

MATHEMATICS ANXIETY SURVEY FOR SECOND AND THIRD STUDY

Students' Mathematics Anxiety Survey

For each of the following statements, please circle the one response that best fits your view.

1) **It wouldn't bother me at all to take more mathematics courses.**

   Strongly Agree Agree Disagree Strongly Disagree

2) **I have usually been at ease during mathematics tests.**

   Strongly Agree Agree Disagree Strongly Disagree

3) **I have usually been at ease during mathematics courses.**

   Strongly Agree Agree Disagree Strongly Disagree

4) **I usually don't worry about my ability to solve mathematics problems.**

   Strongly Agree Agree Disagree Strongly Disagree

5) **I almost never get uptight when taking mathematics tests.**

   Strongly Agree Agree Disagree Strongly Disagree

6) **I get really uptight during mathematics tests.**

   Strongly Agree Agree Disagree Strongly Disagree

7) **I get a sinking feeling when I think of trying hard mathematics problems**

   Strongly Agree Agree Disagree Strongly Disagree

8) **My mind goes blank when I think of trying hard mathematics problems.**

   Strongly Agree Agree Disagree Strongly Disagree

9) **Mathematics makes me feel uncomfortable and nervous.**

   Strongly Agree Agree Disagree Strongly Disagree

10) **Mathematics makes me feel uneasy and confused.**

    Strongly Agree Agree Disagree Strongly Disagree

APPENDIX J

SELF-EFFICACY SURVEY EXAMPLE FOR SECOND AND THIRD STUDY

Directions:

1) **DO NOT ATTEMPT the following problems**.

2) Indicate how well you think you will do on each problem based on the number of points for each problem by filling in the blank in the sentence that follows each problem.

3) Indicate how well you think you will do on the exam based on the number of points the exam is worth by filling in the blank in the sentence at the end of the survey.

Name (Print): ___________________________

Name: ______________________________________

Math Exam 1 Geometric Figures

Directions: Show your work to maximize the credit earned on each problem. You may use any of the geometry tools and a calculator for the exam. The exam is worth 100 points.

1. Use the figure to the right to answer each of the following items as true or false. Circle your choice for each part. **(10 points)**

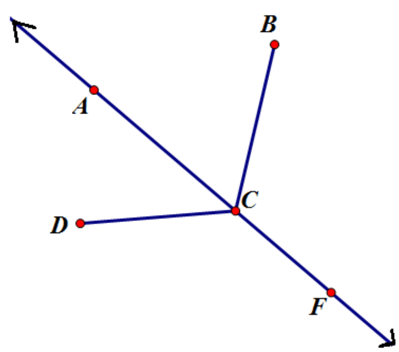
   a. $\overline{BC}$ is a ray. True or False

   b. $\angle ACB$ is obtuse. True or False

   c. $\overline{CD}$ is a segment. True or False

   d. BCD are collinear. True or False

   e. $\angle ACD + \angle DCF = 180^o$ True or False

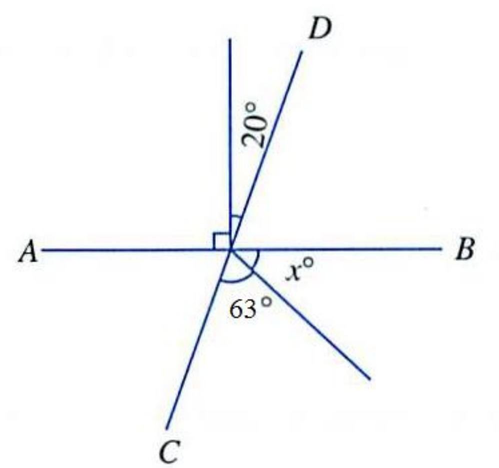


I will receive ____ points on this problem.

2. Using a ruler and protractor, construct rhombus ABCD such that AB = 3 inches, and $\angle A = 120°$. *Measure and label all the angles and sides appropriately*. **(10 points)**

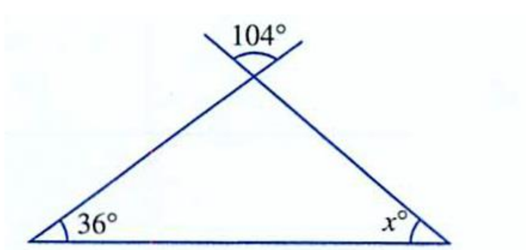
I will receive ____ points on this problem.

3. In the figure below solve for *x* and explain your work by creating a *teacher solution* for the problem. **(8 points)**



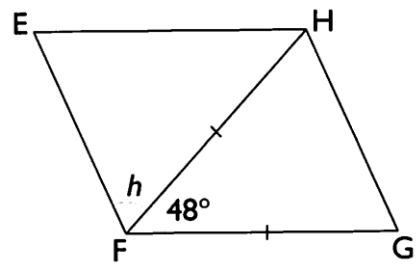
I will receive ____ points on this problem.

4. In the figure below solve for *x* and explain your work by creating a *teacher solution* for the problem. **(8 points)**



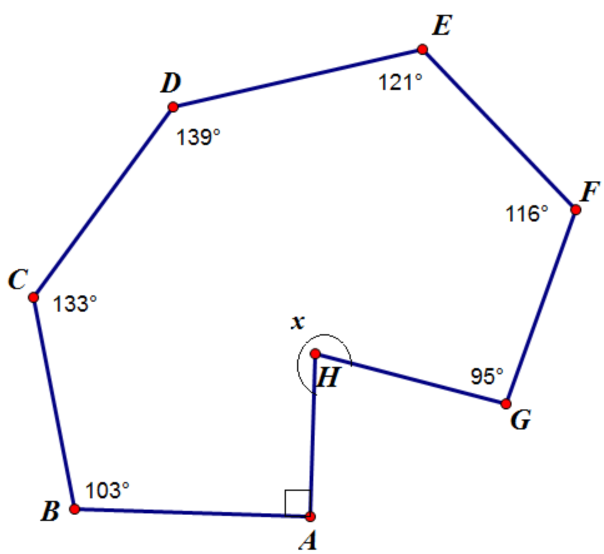
I will receive ____ points on this problem.

5. EFGH is a parallelogram with FH = FG, solve for angle *h* and explain your work for each step by creating *a teacher solution* for the problem. **(8 points)**



I will receive ____ points on this problem.

6. Name the polygon and find the value of the missing angle *x*. **(8 points)**



I will receive ____ points on this problem.

7. For each of the following statements, decide if it is possible or not. **(5 points each)**
   - If it is possible, write POSSIBLE <u>and</u> draw a picture or name the polygon.
   - If it is not possible, write NOT <u>and</u> give a reason.

a) An equilateral triangle that has an obtuse angle.

I will receive ____ points on this part of the problem.

b) A quadrilateral with only one right angle.

I will receive ____ points on this part of the problem.

c) A regular polygon with each interior angle of 150°.

I will receive ____ points on this part of the problem.

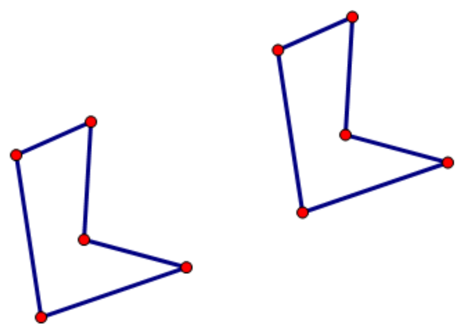
d) A trapezoid that has a line of symmetry.

I will receive ____ points on this part of the problem.

8. Identify at least four properties that are used to classify a square **(8 points)**

I will receive ____ points on this problem.

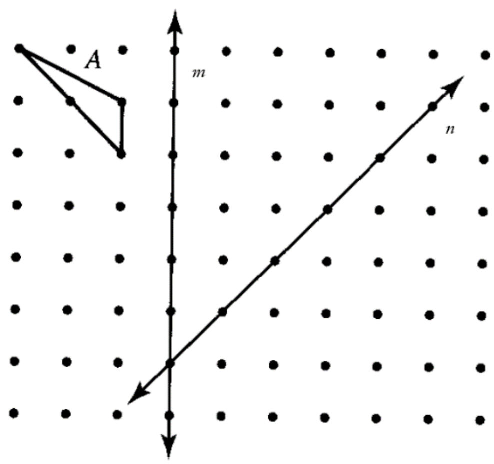
9. What is the relationship between the two images? Discuss at least two properties that are present that helped you determine this relationship. **(8 points)**



I will receive ____ points on this problem.

10. Graham takes Triangle **A** and reflects it about a line *m* to get Triangle **B** and then reflects Triangle **B** about line *n* to get Triangle **C**. He then claims that Triangle **C** is really just a glide reflection of Triangle **A**. Is Graham correct? Why or why not? **(12 points)**

   a) **First**, complete the construction and then evaluate his claim.
   b) If he is correct, provide two properties that support his conjecture.
      If he is incorrect, explain how you could convince him that he is incorrect.



I will receive ____ points on this problem.

This test is worth 100 points total.

I will receive _______ points on this test.

APPENDIX K

SELF-EVALUATION SURVEY EXAMPLE FOR SECOND AND THIRD STUDY

<u>Directions</u>:

1) **DO NOT ATTEMPT the following problems**.

2) Indicate how well you think you did on each problem based on the number of points for each problem by filling in the blank in the sentence that follows each problem.

3) Indicate how well you think you did on the exam based on the number of points the exam is worth by filling in the blank in the sentence at the end of the survey.

Name (Print): ___________________________

Name: ______________________________________

Math Exam 1 Geometric Figures

Directions: Show your work to maximize the credit earned on each problem. You may use any of the geometry tools and a calculator for the exam. The exam is worth 100 points.

2. Use the figure to the right to answer each of the following items as true or false. Circle your choice for each part. **(10 points)**

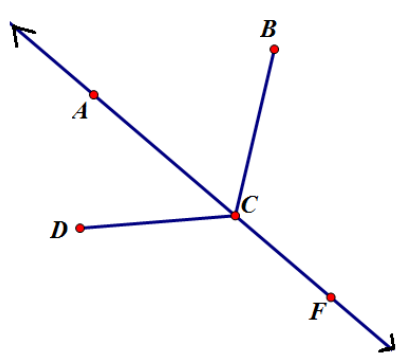
a. $\overline{BC}$ is a ray. True or False

b. $\angle ACB$ is obtuse. True or False

c. $\overline{CD}$ is a segment. True or False

d. BCD are collinear. True or False

e. $\angle ACD + \angle DCF = 180^o$ True or False

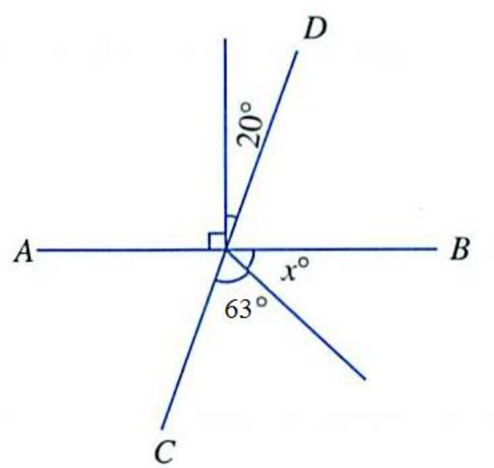


I will receive ____ points on this problem.

2. Using a ruler and protractor, construct rhombus ABCD such that AB = 3 inches, and $\angle A = 120°$. *Measure and label all the angles and sides appropriately*. **(10 points)**

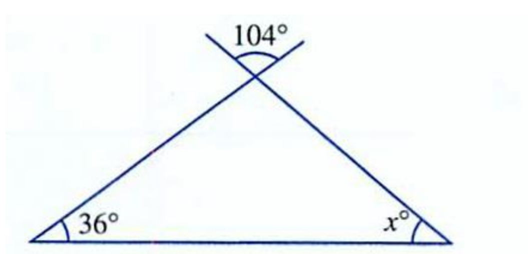
I will receive ____ points on this problem.

9. In the figure below solve for x and explain your work by creating a *teacher solution* for the problem. **(8 points)**



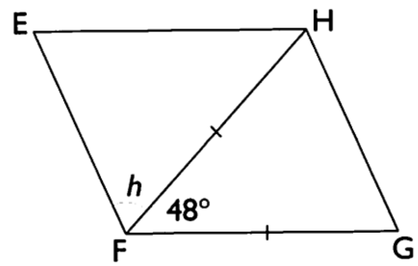
I will receive ____ points on this problem.

10. In the figure below solve for x and explain your work by creating a *teacher solution* for the problem. **(8 points)**



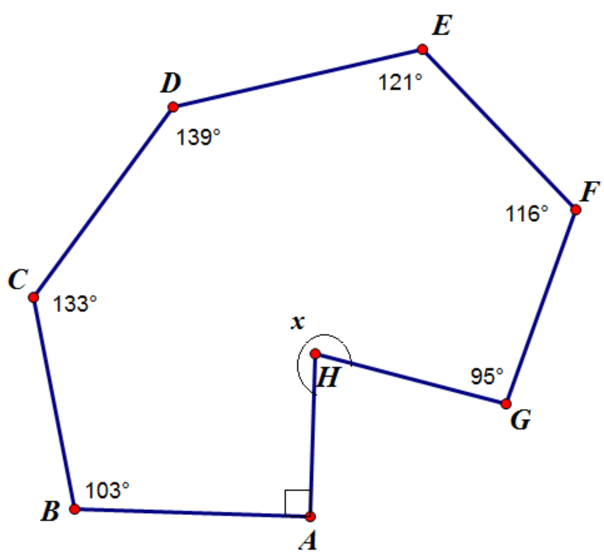
I will receive ____ points on this problem.

11. EFGH is a parallelogram with FH = FG, solve for angle *h* and explain your work for each step by creating *a teacher solution* for the problem. **(8 points)**



I will receive ____ points on this problem.

12. Name the polygon and find the value of the missing angle *x*. **(8 points)**



I will receive ____ points on this problem.

13. For each of the following statements, decide if it is possible or not. **(5 points each)**
    - If it is possible, write POSSIBLE <u>and</u> draw a picture or name the polygon.
    - If it is not possible, write NOT <u>and</u> give a reason.

a) An equilateral triangle that has an obtuse angle.

I will receive ____ points on this part of the problem.

b) A quadrilateral with only one right angle.

I will receive ____ points on this part of the problem.

c) A regular polygon with each interior angle of 150°.

I will receive ____ points on this part of the problem.

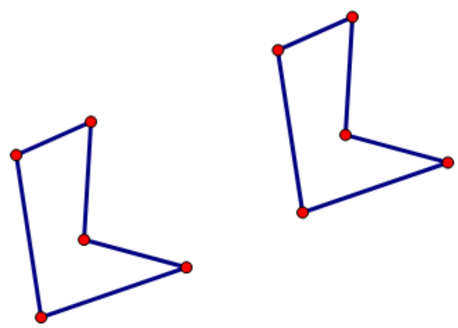
d) A trapezoid that has a line of symmetry.

I will receive ____ points on this part of the problem.

14. Identify at least four properties that are used to classify a square **(8 points)**

I will receive ____ points on this problem.

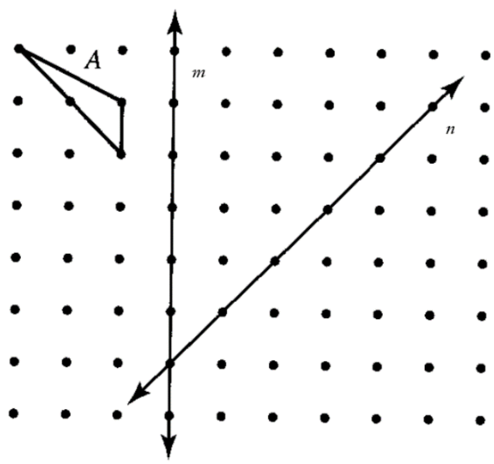
11. What is the relationship between the two images? Discuss at least two properties that are present that helped you determine this relationship. **(8 points)**



I will receive ____ points on this problem.

12. Graham takes Triangle **A** and reflects it about a line *m* to get Triangle **B** and then reflects Triangle **B** about line *n* to get Triangle **C**. He then claims that Triangle **C** is really just a glide reflection of Triangle **A**. Is Graham correct? Why or why not? **(12 points)**

c) **First**, complete the construction and then evaluate his claim.
d) <u>If he is correct</u>, provide two properties that support his conjecture.
<u>If he is incorrect</u>, explain how you could convince him that he is incorrect.



I will receive ____ points on this problem.

This test is worth 100 points total.

I will receive _______ points on this test.

APPENDIX L

MINDSET SURVEY

This questionnaire has been designed to investigate ideas about mathematics intelligence. There are no right or wrong answers. We are interested in your ideas. Using the scale below please indicate the extent to which you agree or disagree with each of the following statements by writing the number that corresponds to your opinion in the space next to each statement.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

____ 1) You have a certain amount of mathematics intelligence, and you can't really do much to change it.

____ 2) Your mathematics intelligence is something about you that you can't change very much.

____ 3) No matter who you are, you can significantly change your mathematics intelligence.

____ 4) To be honest, you can't really change how intelligent in mathematics you are.

____ 5) You can always substantially change how intelligence in mathematics you are.

____ 6) You can learn new things, but you can't really change your basic mathematics intelligence.

____ 7) No matter how much mathematics intelligence you have, you can always change it quite a bit.

____ 8) You can change even your basic mathematics intelligence level considerably.