CREATIVE PROBLEM-SOLVING AND MATHEMATICS ATTITUDES/BELIEFS THROUGH THE YEARS

A Dissertation

by

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ABSTRACT

The purpose of the research conducted in this dissertation was to explore students' beliefs and attitudes towards mathematics learning and teaching when exposed to creative problem-solving techniques. Investigation of creative problem-solving techniques and their effect on students' beliefs towards mathematics may be helpful for retention in the STEM field, improve students' mathematics literacy, and to teach future students. The samples of each study are a reflection on the crucial times in a students' mathematics learning experience. Through the research conducted in Chapter II, I examined elementary students who had positive attitudes towards mathematics and their ability to create solvable word problems. Through the research study data collected in Chapter III, I looked at middle and high school students who attended an interactive STEM summer camp, and through the research data in Chapter IV I examined college aged, pre-service teachers' beliefs in their own mathematics ability and their ability to teach the content.

The results from Chapter II suggest students who had a higher increase in their mathematical attitudes were more likely to create solvable word problems within different contexts. The findings from Chapter III indicate that when students experience carefully crafted instruction, their creativity, or at least their perceptions about creativity, can be influenced. Lastly, the findings from Chapter IV suggest college aged students, more specifically pre-service teachers who are involved in a problem-solving course where the instruction emphasizes flexibility in thought and creativity, develop more self-assurance in their own mathematics ability and teaching of mathematics.

Overall, the results from this dissertation suggest that incorporating various creative problem-solving techniques within students' learning of mathematics leads to more positive beliefs in their ability to understand and perform mathematics successfully. The findings from the three studies conducted add to the current research in mathematics education by demonstrating that the specific pedagogical strategies used to teach mathematics to various levels of students is crucial in the development of each groups' own attitudes. Incorporating creative problem-solving techniques into how mathematics is presented is achievable, and can lead to more students being interested in pursuing a STEM career.
Keywords: Problem-solving, Problem-posing, elementary students, secondary students, pre-service teachers, Project-Based Learning

DEDICATION

I dedicate this dissertation to my parents Russ and Natalie Bevan. You have always been my biggest supporters and cheerleaders. You have pushed me and have known my ability to accomplish things, even when I doubted myself. I would not have been able to achieve this milestone if it were not for the both of you. Love you!

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NOMENCLATURE

CI	Confidence Interval
IRB	Instructional Review Board
MMR	Mixed Methods Research
PBL	Project Based Learning
PP	Problem-posing
PPG	Problem-posing Activities Group
PS	Problem-solving
PSG	Problem-solving Activities Group
PST	Pre-Service Teacher
TEKS	Texas Essential Knowledge and Skills
STEM	Science, Technology, Engineering, and Mathematics
SJR	SCImago Journal Rank
SNIP	Source Normalized Impact per Paper

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1. INTRODUCTION

Through this dissertation study I will examine the idea of creative problem-solving techniques and its effect on students' mathematics perceptions and beliefs along with teaching of mathematics. Creativity allows an individual to explore various strategies and use flexibility in one's problem-solving and thought process to come up with solutions to a problem and/or concept (Bicer et al., 2018; Land, 2013). A misconception is there can be no creativity in mathematics, that everything is already known, and there is one set way to solve a problem (Beghetto, 2007; Bolden et al., 2010; Schoenfeld, 1989). One strategy for addressing this idea is to encourage creative thought through engaging students in creative activities. Creative problem-solving activities include posing of word problems and exploring mathematical ideas through projects that allow for flexibility of thinking. Problem-solving and critical-thinking skills are improved with creative thought. Struggling through the process of solving mathematics problems led to the reflection of students' ideas and allowed for them to experience creativity (Nadjafikhah et al., 2012). Students' beliefs or self-perceptions towards mathematics are sometimes negative, which can lead to a lower number of students wanting to pursue a career or degree in the STEM field. Using creative activities in mathematics can increase one's positive attitude towards mathematics (Akay & Boz, 2010; Candiasa et al., 2018; Guvercin et al., 2014; Seechaliao, 2017; Walkington, 2017; Walkington & Bernacki, 2015). Encouraging students to think more flexibly and allowing for various methods of solving a problem provides more autonomy for students and allows them to take more responsibility for their learning. Investigation of creative problem-solving techniques and their effect on students' beliefs towards mathematics may be helpful for retention in the STEM field and better improve students' mathematics literacy to better teach future students'.

1.1. Statement of the Problem

The relationship between students' beliefs or self-perceptions about their mathematical understanding can influence if a student will pursue a STEM related degree or career. Exposing students to the creative nature of mathematics through problem-solving activities can lead to increased motivation and higher interest in mathematics (Csikszentmihalyi, 1975) and eventually better retention in STEM degrees. Retention in STEM-related degrees is important in the 21st century. STEM careers require successful execution of 21st century skills, which include working collaboratively, effective communication, and solid problem-solving and critical-thinking skills (Markham et al., 2003). The higher demand for students to pursue STEM careers has led to a greater and more intense focus on 21st century skills and thus the desire for mathematics lessons to incorporate these skills. Obtaining positive beliefs towards mathematics begins in elementary school and continues throughout their schooling years. When students do not have the opportunity to develop positive attitudes towards learning mathematics content and solving mathematical problems, a variety of sources can be culprits. A common reason might be their teachers' perceptions about learning mathematics content and solving mathematical problems. Mathematics teachers who have positive beliefs towards mathematics can share their positive beliefs with their students positively influence them to pursue a STEM-related degree and ultimately a career in a STEM field. Developing 21st century skills allow students to approach problems more flexibly and develop solutions using a variety of ways (Bicer, et al., 2018). A student may believe that intelligence is either fixed and unchangeable, or that intelligence is dynamic and changeable (Dweck, 2006, 2009, Shell et al., 2013). There is a shift in paradigm called the mystery and mastery model of giftedness (Matthews & Foster, 2015). The idea of the model is to explain the shift in mindset from a static once intelligent, always intelligent focus to a mindset that dynamic intelligence comes from a focus on practice and effort. Creative problem-solving skills open the mind to new ideas and helps shift the learning model for mathematics toward the mastery model of giftedness. Students who believe intelligence is dynamic tend to set learning goals, engage in better self-regulation, and achieve more (Shell et al., 2013). Students who are more engaged in a subject tend to perform better and have more positive feelings towards learning (Pekrun & Linnenbrink-Garcia, 2012; Shell & Husman, 2008; Shell & Soh, 2013). Exploring creative problem-solving techniques by focusing on the notion that intelligence comes from practice and effort can provide more insight on methods that are effective in maintaining students' interest in learning mathematics. Investigating the effect creative problem-solving has on students' mathematics beliefs or attitudes at the various stages of learning can also help to better understand how students' interests in learning mathematics is related to the pursuit of STEM degrees and careers.

1.2. Purpose of the Dissertation

The primary purpose of this dissertation research was to explore creative problem-solving techniques and the role these techniques play in students' attitudes and beliefs towards mathematics. I examined various methods of creative problem-solving throughout three educational stages. I investigated how elementary students' attitudes towards mathematics are affected after using problem-posing activities and how it effects their mathematical understandings. Secondly, I examined how being involved in a project-based learning environment affects middle and high school students' perceptions about creative problem-solving and mathematics. Lastly, I investigated mathematics pre-service teachers' beliefs concerning how their perceptions about teaching mathematics is affected when they are engaged in a course designed to model creative problem-solving. The findings from these three articles provide useful information about creativity and mathematics and how incorporating creative problem-solving techniques in lessons can improve students' perceptions about mathematics and overall achievement. The research findings from these three articles contribute to an important, and lesser-known area of research and applicability in mathematics education: creativity and its effect on mathematical perceptions and understanding.

1.3. Literature Review

Science, technology, engineering, and mathematics (STEM) degrees and careers are becoming more widespread with the advancement of technology. Success within these STEM-related degrees and careers is closely related to an ability to effectively problem-solve using deep critical-thinking skills. Teachers should devote more time into developing strategies that help promote students' problem-solving skills, develop students' logical thinking skills, and help students analyze and use basic concepts to come to meaningful conclusions (Aladro & Ratner, 1997). Students do not always associate mathematics with positive feelings. Ensuring that students are receptive to, and actively engaged in, mathematical learning, necessitates that mathematics teachers know the content and curriculum goals (National Council of Teachers of Mathematics [NCTM], 2000). Students who do not have a positive outlook on their own abilities in mathematics, or who lack positive feelings toward the subject, often lose interest and become disengaged in the subject (Walkington & Bernacki, 2015). In addition to improving students' positive attitudes toward mathematics, incorporating activities that foster students' creativity in mathematics has been related to problem-solving and problem-posing skills (Nadjafikhah et al., 2012). Creative activities such as problem-posing and project-based learning activities can influence students' attitudes toward mathematics.

1.3.1. Problem-Posing and Students' Mathematics Understanding

Instructional strategies, such as problem-posing, are beneficial for developing students' interest in mathematics and their overall mathematics achievement. "A problem-posing situation is referred to as semi-structured when students are given an open situation and are invited to explore the structure of that situation and to complete it by applying knowledge, skills, concepts, and relationships from their previous mathematical experiences" (Van Harpen & Sriraman, 2012, p. 205). Allowing creative thought to occur in a student's mathematics learning process can increase the student's interest and involvement in learning (Walkington & Bernacki, 2015). Problem-posing actively engages students in the learning of mathematics, and this can lead to greater interest in the subject (Candiasa et al., 2018). Problem-posing also promotes positive outlooks and fosters positive attitudes toward mathematics (Akay & Boz, 2010). Another benefit of problem-posing is that the activity can reveal students' mathematics knowledge and any existing misconceptions they hold (Kilic, 2017). Correctly posing problems is key to understanding mathematics concepts, and the types of problems students pose reflect students' mathematical knowledge (Chang et al., 2012; Toluk-Ucar, 2009). Creative thinking activities, like those found in problem-posing activities, allow students to own their learning and lead to meaningful changes in students' problem-solving and posing.

1.3.2. Creativity and Project-Based Learning

Project-based learning (PBL) is a student-centered pedagogical strategy that helps students learn concepts through discovery and application of skills and has been shown to foster creativity. PBLs allow for multiple subjects to cross and engage student in their learning by fueling their personal interests, which provides more opportunity for students to make meaningful connections (Railsback, 2002; Ratnasari et al., 2018; Wurdinger et al., 2007). PBLs are becoming more well-known and effective pedagogical technique that promotes students' interests in STEM concepts while motivating them to think more creatively and critically. Approaching problems creatively using different methods allows for development of critical thinking and problem-solving skills, as well as developing well thought-out solutions (Bicer et al., 2018). PBL activities rely heavily on problem-solving skills. When students engage routinely in PBLs, their critical thinking skills improve and they can more effectively problem solve (Bell, 2010; Gultekin, 2005). The ability to problem solve an important skill for students to master, particularly as it relates to skills necessary for success in 21st century. There is great need for all students to have good problem-solving and critical thinking skills, and the development of these skills are essential for promoting interest in STEM concepts. Exploration of various mathematics concepts through PBL can enhance students' creativity and critical thinking skills.

1.3.3. Mathematics Creativity and Pre-Service Teachers

A pre-service teacher's perception of their ability is a factor in whether they will be more creative in solving problems or how they will eventually teach. Pre-service teachers who believe in their ability to learn a concept tend to persist in learning, believe they will be successful in the future, and take control over their learning, leading to autonomy (Wigfield & Wentzel, 2007) and more interest in their learning, which effects their confidence and overall ability to think more creatively. Motivation, both intrinsic and extrinsic, are associated with one's self-efficacy and interest in completing a specific task (Perez et al., 2014; Wigfield & Cambria, 2010). Intrinsic motivation comes from interest in the subject and show more positive coping mechanisms, where extrinsic motivation comes from knowing there will be an outcome, positive or negative, and show more tendency to blame others for mistakes (Ryan & Deci, 2000). Motivation, especially intrinsic, is essential to creativity (Sternberg, 2006). Motivation can be enhanced by valuing growth and effort in learning rather than on the performance or grade (Wilkie & Sullivan, 2018). Creativity in mathematics is important and pre-service teachers who have a deep mathematical understanding, and the ability to see the relationship between creativity and problem-solving, are the most successful in incorporating creativity into their own future teaching (Leikin et al., 2013). When students, or pre-service teachers, are motivated and interested in topics, they are generally more willing to put in the extra effort to think more creatively.

1.3.4. Creative Thinking and Students' Learning

Creative thinking is a complex concept. The engagement of creative thought is "when we construct understandings, produce a plan of action, generate an alternative interpretation, understand an event, solve a problem, and even devise a lie to avoid trouble" (Newton & Newton, 2010, p.112). Creativity is a social interaction of three specific parts: the person, field, and domain (Csikszentmihalyi, 1999). Creative thinking is defined as the generation of novel ideas in a given field to contribute to the domain (Csikszentmihalyi, 1999; McIntyre & McIntyre, 2007; Sriraman, 2004). The three aspects to Csikszentmihalyi's (1999) idea of creativity work in a cyclic manner where the domain is a set of information that is known to the person who then produces novel ideas, which are then examined by the field, gatekeepers, or experts, who decide if the idea should be added to the domain (Feldhusen & Goh, 1995). Creative thinking leads to new ideas that can be included in the domain, but before a new idea can be developed, there must be a sense of intrinsic motivation in the person.

Intrinsic motivation is key to developing novel ideas. "In the absence of motivation, ability or potential cannot be transformed into products or performance" (McCoach & Flake, 2018, p. 201). Keeping students motivated is situational for each student. When a student is interested, or motivated in an experience, they are more willing to put forth the effort towards the experience, which Csikszentmihalyi (1975,

1990) theorized as Flow theory. Flow theory helps represent the balance of personal and situational factors and how the interaction of both factors create the best motivational experience (McCoach & Flake, 2018). These researchers (2018) explained how intrinsic motivation occurred when a student believed in themselves and could achieve a goal. Dweck (2009) argued learning is continuous and intelligence is developed. Flexible thinking and divergent thinking align with this idea, because the student has to discover various methods to solving a problem. Encouraging flexible thinking and focusing on the growth mindset fosters healthy attitudes towards learning and the notion that intelligence can be acquired through hard work (Dweck, 2009). Sometimes students believed more in a fixed mindset where intelligence is inherited, which hindered their ability to think more creatively (Dweck, 2006). Students thinking more flexibly fosters healthy attitudes towards learning (Dweck, 2009). When a student is intrinsically motivated and believes they are capable of learning new concepts, they are more willing to create novel ideas.

1.4. Research Questions

During the writing of my dissertation, I focused on investigating students' self-perceptions, attitudes, or beliefs towards mathematics concepts and creative problem-solving. The following three questions frame the three articles for my dissertation.

1. What is the effect of problem-posing activities on elementary students' mathematical understanding and ability to pose solvable word problems?
2. What effect does a STEM-focused summer camp have on students' attitudes towards creative problem-solving? How does gender or grade level influence students' attitudes towards creative problem-solving?

3. How does engaging in creative problem-solving teaching strategies affect pre-service teachers' beliefs towards mathematics and mathematics teaching?

1.5. Method

The methodological approach used while researching and writing this three articles dissertation was different according to the research question for each study and type of data collected. Quantitative statistical analyses were mainly used in two studies. In the second and third studies, I analyzed data using descriptive statistics, 95% confidence intervals (CI), and effect sizes. I calculated effect sizes and confidence intervals for practical significance. In the second study, to determine if there was any influence regarding gender or grade level, I conducted a q-sort to determiner factors. Once these factors were determined, I ran a MANOVA. While conducting the first and third study, I qualitatively analyzed the written responses of the elementary students and the responses to the open-ended questions of the pre-service teachers, respectively. To qualitatively analyze I used constant comparative analysis to determine themes among the responses provided.

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2. POSING CREATIVE PROBLEMS: A STUDY OF ELEMENTARY STUDENTS' ATTITUDES AND UNDERSTANDING

2.1. Introduction

Students who do not possess positive attitudes toward mathematics can often lose interest in the subject. One factor that may influence students' attitudes toward mathematics is their perceptions regarding the degree of creativity and flexibility as well as the freedom of expression offered through engagement in mathematical tasks. For this study, the definition of creativity is the "use of divergent thinking to create one's own novel idea or realistic scenario" (Aljughaiman & Mowrer-Reynolds, 2005; Isaksen et al., 2000; Runco, 2007). There is a general misconception that one cannot be flexible and creative in mathematics classrooms. However, as Devlin (2000) said, "Mathematics is not about numbers, but it is life. It is about the world in which we live. It is about ideas. And far from being dull and sterile as it is so often portrayed, it is full of creativity" (p. 76). In fact, there are varying degrees of creativity assigned to students who engage in mathematics, but their presence in the mathematics classroom largely depends on varied instructional approaches and providing students an outlet to be creative in their thinking. For example, although interest in mathematics generally decreases throughout adolescence, supporting and encouraging creative thought in the learning process has been shown to actually increase interest in mathematics among adolescents (Walkington & Bernacki, 2015). Encouraging flexible thought in mathematics improves both students' mathematics attitudes and understanding, and these are important for student success in everyday life.

Problem-posing is an instructional strategy that utilizes creativity during mathematical instruction. Multiple studies have found that incorporating creative activities positively increases students' attitudes towards mathematics (Akay & Boz, 2010; Candiasa et al., 2018; Guvercin et al., 2014; Seechaliao, 2017; Walkington, 2017; Walkington & Bernacki, 2015) and that problem-posing in particular can increase student engagement (Priest, 2009) and interest (Walkington & Bernacki, 2015). Additionally, posing problems requires higher level thinking and flexibility of thought on the part of the student. Problem-posing instruction can also be beneficial for teachers (Cai & Hwang, 2019; Xu et al., 2019), as it can provide the teacher greater insights into their students' understandings or misunderstandings of various mathematics topics.

Such insights mean that problem-posing instruction can better benefit a classroom than traditional problem-solving instruction. Merely solving problems does not always provide an accurate indication of a student's mathematical understanding because solving word problems requires a certain skill set and mathematical content knowledge (Goldin, 2013). Despite the benefits of the instruction style, the posing of problems is not typically used by mathematics teachers, though it is a strategy that should be included in teaching practices (English, 2020; National Council of Teachers of Mathematics, 2000). This is because few other strategies encourage deeper and richer thinking in mathematics, which can enhance a student's interest and attitude towards mathematics, while improving teacher assessment of student progression in mathematics comprehension.

2.1.1. Fostering Problem-posing in Mathematics Classrooms

Posing problems in the mathematics classroom can enhance students' learning experiences and allow students to produce novel variations in a realistic content. In fact, developing novel methods to solve problems can provide a student greater autonomy in their learning and increase their confidence in mathematics (Lowrie, 2002). However, there is more to learning how to pose problems than simply practicing posing of problems. A groundwork of confidence in independent learning must be supported in order for problem-posing instruction to be successful. Teachers play a vital role in helping foster this confidence, and thus problem-posing, in students and leading students to higher mathematical understanding.

A teacher's main goal should be for their students to successfully learn in his or her classroom. Helping students to develop more positive attitudes towards mathematics can improve their mathematics understanding. This can be affected by the teacher utilizing three instructional practices: a) providing a variety of opportunities to work with mathematical concepts (Calabrese & Capraro, in press), b) sharing and modeling mathematical ideas with other students in a safe environment (English, 2020), and c) challenging activities aligned to the abilities of the students (Fennema et al., 1996; Leikin & Elgrably, 2019). These practices place most of the responsibility of learning on the student rather than the teacher. Providing students opportunities to work through a problem and feel comfortable enough to make mistakes and ask questions can lead to developing more confidence and positive attitudes towards mathematics. Furthermore, facilitating discussions in mathematics classrooms allows for students to discuss their thoughts in an organized manner. In fact, classroom discussions help students pose problems and allow them to talk through their unique problem-solving processes (Gavin & Casa, 2012). Discussions during mathematics lessons can unpack mathematical problems and guide students in their learning because guiding questions can be asked by the teacher to encourage students to elaborate on their thought process (Carpenter et al., 2015). In these ways, teachers can nurture students' learning by providing them ownership of their learning.

Groundwork for independent learning can be supplemented by additional strategies for developing mathematical ideas, including using games (Chang et al., 2011) and diagrams (Charalambous et al., 2003) to assist in the construction of word problems. Many other methods exist for helping students to create better problems (see Cankoy, 2014). With supportive learning environments and the ability to engage with challenging mathematical concepts, students can effectively learn using problem-posing strategies. Strategies and implementation may look different from classroom to classroom, but the end goal remains the same: engaging students in the creation of their own mathematical problems.

2.1.2. The Benefits of Problem-posing

There are a variety of definitions for what problem-posing entails. One definition frames problem-posing as the process of students formulating meaningful problems using personal interests (Stoyanova & Ellerton, 1996). Problem-posing can be both the creation of a novel problem and the slight restructuring of given problems (Silver, 1994). There are three classifications of problems students can pose: free, semi-structured, and structured. “A problem-posing situation is referred to as semi-structured when students are given an open situation and are invited to explore the structure of that situation and to complete it by applying knowledge, skills, concepts, and relationships from their previous mathematical experiences” (Van Harpen & Sriraman, 2012, p. 205). By incorporating manipulatives, visual aids, or equations, teachers can help guide students through the process of creating a novel problem based on their own interests. This allows for some structure in their learning while still allowing students freedom to develop their own problems.

This feature of problem-posing requires creative thinking and a more complex understanding of mathematical concepts from students than strictly solving word problems. Problem-posing also requires students to use previous knowledge and real-world applications when developing problems. The real-world application and creativity used in problem-posing instruction necessitates that students think flexibly and critically. Additionally, increasing opportunities for students to use creativity and real-world applications in their learning allows them to become more engaged, leading to more positive attitudes toward mathematics (Cankoy, 2014; Chang et al., 2011; Sugito et al., 2017; Sung et al., 2016). This is perhaps because when students use their own interests or their classmates’ or their teacher’s names in problems they pose or pose problems about a particular motivating topic, they realize that mathematics is relevant to their personal interests and lives (Winograd, 1991). Additionally, the autonomy itself that students experience when problem-posing has been shown to increase students’ attitudes and interest towards mathematics (Chang et al., 2011; Rosli et al., 2014; Toluk-Ucar, 2009). Problem-posing can provide a powerful learning experience for students while allowing them to realize that mathematics can be a creative subject, which can potentially lead to increased interest in the topic and improved mathematics understanding.

Problem-posing can also benefit teacher lesson planning and instruction. Because misconceptions are common when learning mathematics concepts, providing opportunities to pose problems allows for teacher insight into their students' alternate understandings or prior mathematics knowledge (Kilic, 2017). Composing a solvable problem can indicate a student's mathematical understanding of various concepts, and a poorly written one can reveal underdeveloped aspects of a student's mathematical understanding (Chang et al., 2011; Toluk-Ucar, 2009). With the information attained from a student's posed problems, a teacher can introduce specific lessons and strategies into the classroom to better aid that student's or a group of students' learning and mathematical understanding.

A previous study conducted by Bevan et al. (2019) examined a group of students who displayed positive attitudes towards mathematics during a problem-posing intervention ($N = 35$). The researchers identified the students who had the highest increase in scores from a pre and postsurvey concerning their attitudes towards mathematics ($n = 11$). During the current study, researchers examined the work of these particular students qualitatively to further understand how they posed problems as well as the relationship between these students' attitudes and mathematics understanding. More broadly, the researchers' purpose for the current study was to determine the effect of problem-posing activities on elementary students' mathematical understanding and ability to pose solvable word problems.

2.2. Methodology

Within the larger multi-year study (i.e., Bevan et al., 2019), the present study was quasi-experimental and utilized a subset of data (n = 11). The primary focus of the present study was to understand how a problem-posing intervention can increase students' mathematical understanding and ability to pose solvable word problems. The unique aspect of this study is the application of a fine-grained analytic technique to understand similarities among students' problem-posing responses.

2.2.1. Intervention

Students worked in two small groups at mathematics learning centers. One group was engaged in problem-posing instruction and the other problem-solving instruction. The activities at the learning centers were led by university preservice teachers (PSTs). The PSTs met weekly with university mathematics education researchers to discuss and demonstrate weekly intervention procedures. The estimated completion time of the small group learning center activities ranged between 15 and 20 minutes, and the PSTs modeled the process required for that week's activity. Guiding questions were used for both groups of students to assure student understanding of the weekly activity content. Students were reminded to employ their creativity in posing problems. They posed their own written problems based on the use of pictures, manipulatives, or mathematical expressions. The PSTs led a discussion with the problem-posing group (PPG) of students focused on their written posed problems and discussed whether the posed problems were accurate, used operations correctly, and were solvable. Students in the problem-solving group (PSG) followed a similar format during the small group activities but were given problems to solve rather than being asked to pose their own problems.

Activities were chosen to determine if the PPG used equations to develop a word problem, which allowed researchers to evaluate if there were connections between the problem posed and the equation provided. For example, during week five, elementary students worked in pairs and were asked to pick an Easter egg that contained a letter corresponding to an equation and then directed to pose their own word problem based on the provided equation. As depicted in Figure 2.1 and 2.2 younger students' content focused on addition and subtraction while upper elementary student content included addition, subtraction, multiplication, and division.

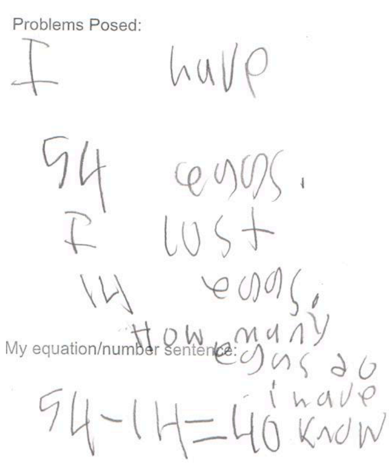
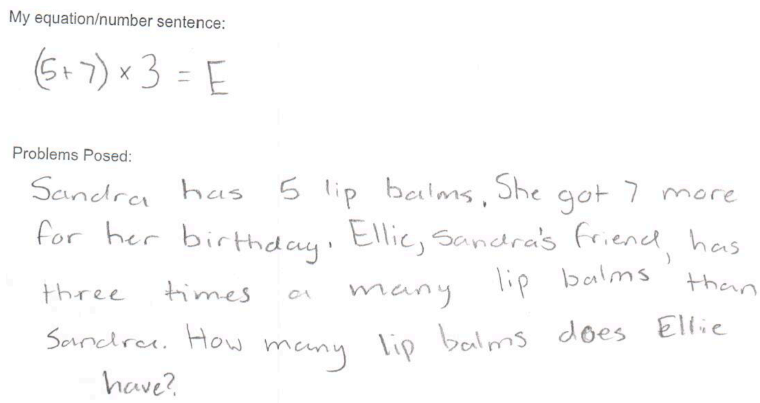


Figure 2.1 Second Grade Easter Egg Responses


My equation/number sentence:

$(5+7) \times 3 = E$

Problems Posed:

Sandra has 5 lip balms, She got 7 more for her birthday. Ellie, Sandra's friend, has three times a many lip balms than Sandra. How many lip balms does Ellie have?

Figure 2.2 Fourth Grade Easter Egg Responses

2.2.2. Participants

The targeted elementary students (*n* = 11) had the highest increases in attitude scores from the larger study. All participants were enrolled in two Title 1 schools within one district. The demographics for these two schools mirrored those of the district: 47.5% White, 27.6% Hispanic, 21.2% African American, and 4% Others. Parental consent and student assent were obtained through the university Internal Review Board

2.2.3. Instruments

Researchers developed four problem-solving and two problem-posing tasks to be administered for preintervention and postintervention. The difficulty of the tasks was adapted to each grade level (2nd and 4th) based on the expected grade-level mathematical abilities of the students. For example, second graders were asked to pose a one-step problem with addition while fourth graders were asked to pose a two-step problem with multiplication (contact authors for grade-level examples). Two mathematics education professors not affiliated with the research vetted the tasks and the rubric used to assess student responses. The pre- and post-intervention problem-solving and problem-posing tasks were first administered at the beginning of the semester in early January before the intervention activities began. The exact same problem-solving and problem-posing tasks were administered four months later at the end of the semester in early May.

The researchers developed a problem-posing rubric to rate the problems posed on structure or context, mathematical expression, and appropriateness. Each of the pre- and post-intervention tasks were evaluated using the Problem-Posing Rubric (see Appendix) and Problem-Solving Rubric (contact authors for a copy). The problem-posing tasks (n = 2) were each worth 6 points each for a total of 12 points and the problem-solving tasks (n = 4) were each worth 3 points each for a total of 12 points, with a possible 24 points maximum for the entire task.

For the purposes of this study, we only focus on the results from the problem-posing tasks. The pre- and post-intervention problem-posing tasks were evaluated by two researchers while accounting for inter-rater reliability. The researchers graded the pre- and post-intervention problem-solving and problem-posing tasks together. Content validity of the problem-posing part of the study was verified by two eminent mathematics professors who possess strong research skills and various problem-posing publications and who were not part of this research study. Once these scores were calculated, total scores and differences of scores between pre- and post-intervention problem-solving and problem-posing tasks were calculated. Researchers developed a short three-question survey that was administered to all participants for the purpose of measuring the elementary students' attitudes toward mathematics, problem-posing, and problem-solving. It was administered as a presurvey prior to the first activity and at the end of the intervention as a postsurvey.

2.2.4. Data Analysis

After identifying the target students (n = 11), researchers qualitatively analyzed responses from their pre- and post-intervention problem-solving and problem-posing tasks and two of the ten activity intervention tasks (i.e., Easter egg and popsicle stick random equation selection activities). Qualitatively analyzing the students' responses to the different tasks gave insight into students' mathematical understanding. Researchers employed descriptive coding (Saldaña, 2016) and keywords-in-context (Leech & Onwuegbuzie, 2007). The process included reading responses; identifying common themes, words, and methods; and triangulating results. Initial coding was used to find similarities and differences between the students' responses. Each student's responses were coded first on whether a problem was posed (i.e., did the student ask a question or write a statement?). Once this step was determined, each posed problem was classified as solvable or not. Researchers labeled the responses as solvable if there was enough information in the word problem to reach an answer, and responses were labeled as unsolvable if there was not enough information provided in the word problem posed to solve it. Responses were then analyzed using four criteria to determine if the posed problem had a relationship to the equation provided. Data were then coded and categorized individually and then cross compared into themes. Coding discrepancies were resolved until there was a 100% agreement (Olson et al., 2016).

2.3. Results

In order to delve deeper into the mathematical understanding of the targeted students than initially done in the Bevan et al. (2019) findings, we examined the students' posed problems through a variety of lenses. First, the researchers examined the posed problems to initially determine whether they were solvable or not. There was a total of 70 available responses, with 40 being categorized as solvable posed problems and 30 as unsolvable posed problems. An example of an unsolvable posed problem is the following written by a second-grade student: "Thirets [sic] 2 bears at the zoo, 10 wolfs [sic], 7 tigers, 3 zebras and 40 giraffe [sic]." This student did not pose a question stem for the problem thus leaving it unsolvable. On the opposite end, a solvable posed problem included enough information and context to solve the problem. An example of a solvable problem was, "I have 54 eggs. I lost 14 eggs. How many eggs do I have know [sic]?" Within the responses that were coded as solvable, the problems posed were further analyzed using the following lens: whether the problem was realistic, problem context, flexibility of using a variety of computational terminology, and correct alignment to equation.

2.3.1. Realistic

Writing a word problem may seem somewhat straight forward but making sure the problem is both solvable and realistic takes an extra level of knowledge and computational and contextual understanding. Most of the problems posed were considered realistic, but a few could be labeled as unrealistic to an adult audience. For example, a solvable and realistic problem written by one of the second-grade students stated, “There are 10 wolfes [sic] and 7 tigers. How many wolfs [sic] and tigers are there together?” This student was using a picture provided to the group and wrote the problem in a format that would allow one of their classmates to solve the problem. There was enough information written to set up an addition problem and solve for the total number of tigers and wolves. Figure 2.3 shows an example of a solvable but unrealistic word problem: “Kloe has 46 cats. Heidi gave her 67 more cats. Kloe gave 14 cats to Tayden. How many cats does Kloe have left?” This particular problem was written by a second-grade student and was based off an equation, 46 + 67 − 14 =, chosen from an Easter egg during the Easter egg activity. This word problem could be viewed as unrealistic because there is not much context on why an individual would have so many cats.

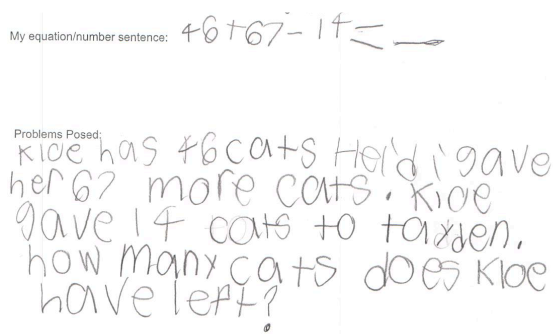
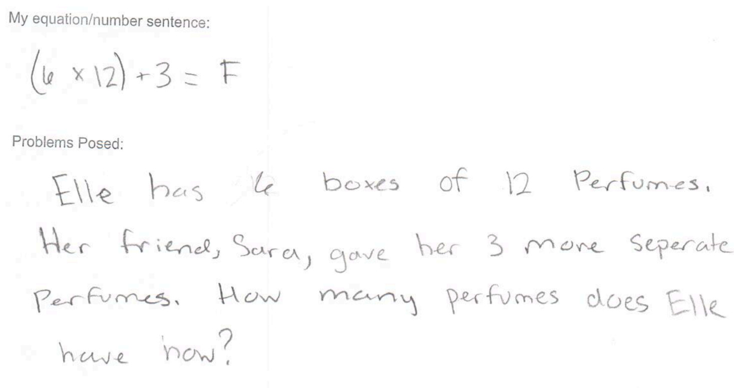


Figure 2.3 Solvable but Unrealistic Word Problems

2.3.2. Problem Context

Another characteristic within the responses is how the students wrote complex problems involving different names. These names were most often the names of their classmates and teacher with whom they were familiar. Students also used their creativity in using different contexts for their problems. During the pre- and post-intervention problem-posing tasks, students were given pictures and asked to write a problem. Students tended to use the contents of the pictures (zoo animals or cake) when posing problems during this activity, but when students were asked to write a problem in the Easter egg and popsicle stick activities, they would use various contexts that were not eggs or sticks. Students chose to use cars, animals, pencils, food, and beauty products instead when posing problems during these two activities. For example, one of the students picked the equation $(6 \times 12) + 3 =$ during the Easter egg activity and was asked to write a problem using the equation. This student decided to use perfume as the context and wrote, "Elle has 6 boxes of 12 perfumes. Her friend, Sara, gave her 3 more separate perfumes. How many perfumes does Elle have now?" (see Figure 2.4). Another example reflected the equation $14 + 14 + 14 + 14 =$: "My dad mad [sic] 14 pizzas. I order 14 more. Somebody give [sic] us 14. I by [sic] 14 pizzas. How many pizza [sic] do we have at [sic] all?" A majority of the students used various familiar contexts while posing their problems. In fact, we found that when students are allowed to write problems in a context, they are familiar with, they are more likely to formulate a solvable and interesting word problem.


My equation/number sentence:

$(6 \times 12) + 3 = F$

Problems Posed:

Elle has 6 boxes of 12 Perfumes. Her friend, Sara, gave her 3 more seperate Perfumes. How many perfumes does Elle have now?

Figure 2.4 Example of Student Work with Different Context

2.3.3. Flexibility of Operation Terminology

One characteristic that stood out in student responses was that most students used correct terminology to indicate either subtraction, addition, or multiplication. An interesting finding was the problems posed by the students in the pre-intervention problem-posing tasks and in the post-intervention problem-posing tasks used correct vocabulary to represent a question by asking “how many” to represent finding the missing result. Most of the students asked their peers to find the total amount of whatever objects they used in their posed problem and used the phrases “in all” or “together” frequently when doing so. This was not always the case, however. One second-grade student wrote, “I whent [sic] to the zoo and saw 7 tigers and 3 bears how many more tigers did I see than bears?” (see Figure 2.5). This student was using a picture provided to the group, but rather than ask for a total of bears and tigers, this student compared the number of tigers to the number of bears. Solving a comparative problem is challenging but creating an original comparison problem requires a high level of mathematical understanding.

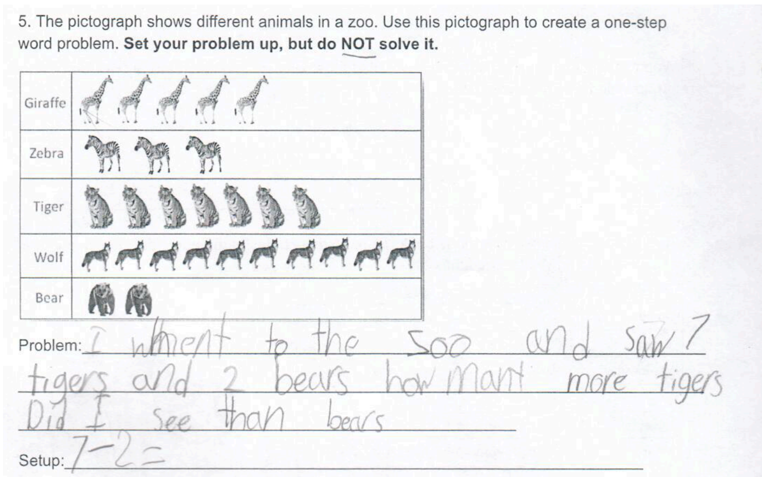


Figure 2.5 Example of Student Work Using Various Operational Terminology

Another indication of flexibility in operation terminology was when students used the word “more” to represent addition. One student wrote, “Ramsey had 40 pieces of candy she gave 10 to Adrianna then went to buy 15 pieces more how many pieces does she have now.” This student’s posed problem indicates the knowledge of “more” representing addition and the phrase “gave 10 to Adrianna” as subtraction. Indications of flexibility of operation terminology had the potential to involve more abstract thinking as well.

One fourth grade student developed an equation based off the operators and numbers they selected during the popsicle stick activity (22, +, 15, ×, 6). They wrote, “Teagan has 22 lip balms. She bought 15 more over the summer. Elle has 6x as many than Teagan. How many balms does Elle have?” What is interesting with this problem is the student understands the relationship between “×” and times; in an earlier problem they wrote out times, but with this problem they used the "×" symbol within their word problem to denote "times" or multiplication. By using various terms and methods to represent operations within their problems, the students demonstrated not only their awareness and understanding of certain mathematical vocabulary terminology but also that they were able to successfully use these terms to align with an equation. Additionally, most proved to be successful in their use of the terminology. Table 2.1 lists out the progression of each student's ability to pose problems from the pre-intervention task, through the two weekly activities, and finally through the post-intervention task.

Table 2.1 Student Progression Throughout Intervention

Student #	Pre-Task	Activities	Post-Task
2.1	Left both tasks blank.	Wrote one join problem "how many all together?" Wrote a 2-step separation problem – "how many toys does he have now?"	Created two join problems both of which asked, "how many all together?"
2.2	Created a solvable joining problem and asked, "how many in all?"	Wrote one separation problem – "how many toys does he have now?" Wrote a 2-step joining problem – "how many do I have now?"	Created a similar joining problem as the pre-task and asked, "how many now?"
2.3	Left both tasks blank.	Wrote one separation problem – "how many toys does he have now?" Wrote a 2-step joining problem – "how many does he have now?"	Created two multistep problems rather than leaving the problem blank and asked, "how many are there?"
2.4	Attempted to create a problem, however unsolvable. Left one task blank.	Wrote one separation problem – "how many does he have now? Wrote a 2-step joining problem- how many does he have now?"	Created two problems rather than leaving problem blank and asked, "how many are there total?"
2.5	Created two joining, solvable problems and asked, "how many in all?"	Wrote a 2-step separating and joining problem – "how many does she have left?" Wrote a 2-step joining problem – "how many does she have now?"	Wrote similar joining problems as in the pre-task and asked, "how many in all," but both problems lacked solvable context.

Table 2.1 Continued

Student #	Pre-Task	Activities	Post-Task
2.6	Attempted to create two problems, however both were unsolvable.	Wrote one separation problem – "how many toys does he have now?" Wrote a 2-step joining problem – "how many does he have now?"	Attempted to create two problems, however both were unsolvable
2.7	Attempted to create two problems, however both were unsolvable.	Wrote two 2-step separating and joining problems – "how many do I have left?"	Created a complex separation comparison problem rather than leaving task blank and asked, "how many more tigers did I see than bears?"
2.8	Attempted to create two problems, however both were unsolvable.	Wrote a multi-step joining problem – "how many in all?" Wrote a 2-step separation and joining problem – "how many in all?"	Attempted to create two problems, however both were unsolvable
2.9	Attempted to create two problems, however both were unsolvable.	Wrote a multi-stepped joining problem– "how many in all?"	Created a problem with local location as context and asked, "how many are there now?"
4.1	Attempted to create two problems, however both were unsolvable.	Wrote four 2-step multiplicative comparison and joining problems- – "how many does she have?"	Created a solvable word problem with context and asked, "how much did they spend."
4.2	Attempted to create two problems, however both were unsolvable.	Wrote a 2-step separating and joining problems – "how many do I have left?"	Attempted to create two problems, however both were unsolvable

2.3.4. Correct Alignment to Equation

Posing word problems can be an enjoyable activity for students, and it can enable them to gain interest in learning mathematics; however, one of the most important components of problem-posing for students is the ability to align the word problem posed to an equation. Word problems are created within scenarios that hopefully are relatable to students and can enable them to strengthen their problem-solving skills. Creating a word problem based off an equation without context requires an even higher level of mathematical understanding. Out of the posed problems denoted as solvable, 88% of them aligned with a correct equation. Table 2.2 breaks down only the problems that students correctly aligned to their equations by the following categories: joining, separation, comparison, or multiple operations. Word problems considered as joining included addition in the equation assigned to the student and the problem they posed. Posed problems considered to be separation included subtraction within the equation the student chose and the problem they posed. Comparison problems were more complex and used the phrase “more than,” and multiple operations were two-step problems that included addition and subtraction or addition and multiplication.

Table 2.2 Categories of Problems Posed

Student #	Joining	Separation	Comparison	Multiple Operations
2.1	2	1		
2.2	4	1		
2.3	2	1		
2.4	3	1		
2.5	3			1
2.6	1	1		
2.7		1		2
2.8	1			1
2.9	2			
4.1	1			4
4.2				2

In certain weekly activities that the students engaged in, they chose an equation from either Easter eggs or popsicle sticks and were asked to pose a problem that reflected the equation. During the popsicle activity, one fourth-grade student wrote a problem to align with the popsicles they chose and the numbers or operators they contained (15, 20, −, +, 14). The equation they created was 20 + 15 − 14 =. Based off the equation the student created, they posed the following problem: "I had 20 pickels [sic]. I went to the store and bought 15 more then I gave 14 away to my friend how many pickels [sic] did I have left?" We noticed the student understood the relationship between joining items they already possessed and items they bought at the store, and they successfully related this understanding to the operation of addition. This student also understood that giving away pickles meant they would have a smaller number of pickles and was able to correctly connect this transaction to the operation of subtraction. Examining these problems demonstrated that some students had the ability to make a strong connection between the problems they posed, and the equation given to them.

2.4. Implications

Including activities such as problem-posing into a mathematics curriculum helps improve students' attitudes towards mathematics and mathematical understandings. Although teaching is complex and incorporating a new teaching strategy can be difficult, the benefits of doing so may outweigh the challenge. Teachers can utilize problem-posing activities in their lessons to provide opportunities to create more interest among students in their own learning. Based off the examples provided in our study, a teacher can use their students' responses to gauge their mathematical knowledge and where there is room for improvement. For instance, as shown in Table 1, our participants wrote problems involving joining "things" and asked for a grand total or "how many are there now?" Students were also able to connect words to varying operations. Relational thinking is the foundation for better understanding of more complex and abstract concepts children will learn throughout their mathematics education (Carpenter et al., 2015).

Teachers can use this information to direct their lessons to more complex types of problems and help work with their students on how to write subtraction or comparison problems. For example, if Table 2 reflected a particular teacher's classroom, we suggest they engage in working with students to write separation and multiple operation problems because most students showed proficiency in writing joining problems. Finally, working with students and helping guide them through their learning and talking through their processes can help teachers gain further insights into students' thinking and engage students in their own learning. Our participants were second- and fourth-grade students who sometimes had difficulties writing out their thoughts and speaking through the problems they posed. Teachers can ask guiding questions, either individually or as a class, to encourage their students to verbalize orally and through the written word in order to build their confidence in mathematics (Carpenter et al., 2015). Embracing different activities can enhance learning in the classroom and increase students' interest in mathematics.

2.5. Conclusion

There are many benefits of integrating problem-posing activities into early mathematics classrooms. One benefit is developing flexibility in students' thinking when having to create solvable word problems. When we examined the students (n = 11) from the prior study (Bevan et al., 2019) who experienced the highest increases in their mathematical attitudes, we determined they were more likely to create solvable word problems within different contexts. We also agreed with other researchers (Chang et al., 2011; Toluk-Ucar, 2009) in that examining the responses from second- and fourth-grade students provides insights into their levels of mathematical understanding and also where there is room for improvement. Our findings help further the literature by demonstrating that elementary students who are engaged in problem-posing activities in their mathematics classroom can improve their understandings towards mathematics (Chang et al., 2011; Sugito et al., 2017; Sung et al., 2016).

Most students, in fact, showed certain improvements from before the intervention to after the intervention. Improvements included posing word problems that were solvable and sometimes contained multiple steps. Students demonstrated a strong ability in connecting the word problem they created to the chosen equation. Incorporating different contexts within problems motivated student creativity, autonomy, and interest in posing and solving problems because the students were able to choose the context of the problem. Guiding students by asking them to pose semi-structured problems by providing them pictures or other supports when building an equation provides a balance between giving the student freedom in their learning and making sure the student is learning the correct content. Finally, allowing students the freedom to create problems based off what interests them promotes ownership in their learning and provides teachers a window into their students' learning.

Posing of word problems involves more than writing the problem; it also includes discussion about the context and solvability of a word problem produced by a student (Gavin & Casa, 2012). During the current study, discussions took place in small groups with the assigned PST and the students' peers and allowed students to exchange and discuss their posed problems. These discussions allowed for students to grow in their mathematical understanding. Ultimately, aiding elementary students in gaining confidence in their own mathematics skills through problem-posing can lead to deeper mathematical understandings and more interest in the subject. Allowing for creativity in the mathematics classroom allows for more opportunities to encourage positive attitudes towards mathematical concepts and the application of mathematics in real-world settings.

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3. STEM PROJECT-BASED LEARNING FOSTERING MATHEMATICAL CREATIVITY

3.1. Introduction

Mathematics, by its nature, is a creative subject. Mathematics is also a subject that requires well-developed critical-thinking and problem-solving skills, which are becoming increasingly important with the growth of science, technology, engineering, and mathematics (STEM) related careers. Far from being in conflict or diametrically opposed with one another, creativity along with both critical-thinking and problem-solving skills are necessary for mastering mathematical thinking. In fact, one method for developing an individual's critical-thinking and problem-solving skills is by fostering their creativity.

What is creativity, and why is it important? Creativity is the ability to generate novel ideas in a particular field and to come up with a variation in a domain (Csikszentmihalyi, 1999; McIntyre & McIntyre, 2007; Sriraman, 2004). There is, however, a misconception regarding creativity and "novel" ideas; namely, that for something to be considered creative, it must be a groundbreaking new idea. In actuality, along with groundbreaking ideas, small changes and adjustments to existing ideas and knowledge are manifestations of creativity. For instance, engaging in creative thought is "when we construct understandings, produce a plan of action, generate an alternative interpretation, understand an event, solve a problem, and even devise a lie to avoid trouble" (Newton & Newton, 2010, p.112). Creativity allows an individual to explore various strategies and flexibility in one's problem-solving methods and the thought process utilized in generating solutions to a problem or concept (Bicer et al., 2018; Bicer et al., 2020; Land, 2013). Therefore, creativity is important to foster within students who are engaging with STEM project-based learning (PBL) and expected to learn mathematics content.

Teachers can help foster students' creative thinking by implementing appropriate instructional methods, such as STEM PBL. This is because engaging in STEM-related activities during PBL is a special case of enactivism learning (e.g., Sumara & Davis, 1997). In fact, the essence of a STEM PBL activity is trial and error and working through a problem. These characteristics make STEM PBL an ideal environment for teachers to foster creativity during the journey of discovery and learning of mathematics and other STEM subjects (Senne et al., 2016). The simple implementation of STEM PBL, however, is not enough to improve students' learning and creativity.

Teachers affect students' performance in and perceptions of STEM subjects and concepts through their instruction. It is, therefore, important for a teacher who integrates creative thinking in their classroom to have a deep understanding of the concepts being taught to demonstrate to his or her students how to creatively think about, discuss, and solve problems. A lack of adequate content knowledge may lead to confusion and ultimately a floundering of creative solutions. Teachers must also have patience during their students' learning process, for it is a process that takes time, and students need time to "incubate" their ideas (Hadamard, 1945; Patrick, 1941; Wallas, 1926). With adequate training and support, teachers can cultivate students' creative thinking, and by extension critical-thinking and problem-solving skills, by integrating STEM PBL activities.

3.1.1. Creativity Leading to Critical-Thinking and Problem-Solving Skills through Project-Based Learning

Creativity can be fostered through different teaching methods, one being PBL. PBL activities are beneficial in helping students connect to the topic being taught on a more meaningful level. This student-centered pedagogical strategy helps students learn concepts through discovery and application of skills. Use of PBL activities enables teachers to connect multiple subjects and incorporate students' interests within a single activity, which has been shown to help students make meaningful connections between their prior knowledge and new knowledge (Railsback, 2002; Ratnasari et al., 2018; Wurdinger et al., 2007). PBL activities focus on skills such as the ability to collaboratively work and communicate as a team while using technology, creative thought, problem-solving skills, and critical-thinking skills, which are what Markham et al. (2003) defined as 21st century skills. Because of this, PBL activities are becoming increasingly recognized as a beneficial method in the improvement of 21st century skills, and their use is becoming an increasingly popular and effective strategy for fostering students' understanding of the connections between multiple subjects while motivating them to think more creatively and critically.

The format of PBL activities positions students in a central role of their learning. During these activities, students are provided limitations or constraints on the time and the materials they can use with minimal guidance from their instructor. These limitations encourage students to think creatively and "outside the box" or non-traditionally on how to best reach a final solution and artifact (Tharp & Reiter, 2003).

Importantly, students' learning and thinking is self-directed. This aspect of PBL instruction provides students with opportunities to innovatively identify solutions related to real-world issues (Blumenfeld et al., 1991). One outcome of engaging in PBL is that students improve their critical-thinking skills and more effectively solve problems (Bell, 2010; Gultekin, 2005, Sasson et al., 2018). This is because students must utilize critical thinking and problem-solving effectively in order to succeed in PBL activities.

Thinking creatively or non-traditionally is critical student success in PBL because students may initially use methods to solve a PBL activity that may not be the best or most effective approach. As such, there are many opportunities for learning to occur through trial and error during PBL activities. This is important, because making mistakes on projects can help students learn how to process and fix their errors, which allows for deep thought and reflection and prompts the development of novel solutions. Approaching problems creatively and using new or different methods than previously taught is both necessary to achieve success in PBL and ultimately allows for the development of critical-thinking and problem-solving skills while enabling one to produce extensive solutions (Bicer et al., 2018; Cooper & Heaverlo, 2013). Placing more emphasis on the process of learning mathematical concepts through PBL activities allows for errors to occur, and the need to analyze those errors and identify alternative solutions may encourage more creative thought and critical thinking.

3.1.2. Creativity and Mathematics

Students' mathematical creativity may be more visible during PBL activities than traditional approaches. This is because students are allowed to explore complex problems and be creative in selecting strategies for solving those problems. They are not limited to rote methods of problem-solving. For some individuals, the first thought that may come to mind when hearing the words "creative" and "mathematics" together is that there can be no creativity in mathematics or that in mathematics everything is already known and there is a set way to solve a problem (Schoenfeld, 1989). However, this interpretation of mathematics could not be further from the truth.

Defining mathematical creativity is complex, but it can be expressed through the four-stage Gestalt model and Csikszentmihalyi's model (Sriraman, 2004). The four stages consist of preparation, incubation, illumination, and verification (Hadamard, 1945; Patrick, 1941; Wallas, 1926). Preparation is the process of collecting ideas and thinking about the problem. During the second stage, or the incubation stage, students put ideas aside and process subconsciously, giving time to truly develop a novel solution. The third stage, illumination, occurs when least expected, and it is at this stage that the idea or solution appears, which then leads to the fourth and final stage: verification. Verification is the stage when the idea or solution is explained and verified. Cycling through the four stages of the Gestalt model allows students to better witness the creativity of mathematics.

Creativity itself is a process consisting of three components (field, domain, and individual) that all interact with each other to develop creative thought

(Csikszentmihalyi, 1999). As stated by McIntyre and McIntyre (2007), creativity is "a domain of knowledge, a field or social organisation that understands that knowledge; and an individual whose task it is to make changes in the domain" (p.17). This idea of creativity can be found within PBL activities. This is because the students are given a problem that was developed and viewed as important within the domain and by the field, and the individual is given the opportunity to think about and understand the problem differently and possibly make changes to the domain. The added sense of agency and deep understanding this process affords students is important for effective learning. In fact, incorporating PBL activities in high school mathematics courses is one way to provide students opportunities to understand how particular concepts are relevant to the real world while allowing for creative agency to explore those concepts in greater depth.

3.1.3. Secondary Mathematics and the Importance of PBL

Mathematics concepts gradually become more abstract throughout a student's career. By the time students are in secondary school, they can have a difficult time finding reasons for why they are having to learn particular concepts. Findings from previous research indicate that PBL activities can improve secondary students' understanding of mathematics and their ability to connect their knowledge to real-world applications (Efstratia, 2014; Gijbels et al., 2005; Lee, 2018). When students are more confident in their mathematics and science skills, they are more likely to be interested in pursuing a STEM-related field (Chemers et al., 2011; Kesan & Kaya, 2018; Robnett et al., 2015; Wang, 2013). Connections to real-world applications help make abstract concepts in mathematics become more concrete, which can help foster increased interest and participation.

Engaging in PBL activities has also been shown to improve mathematical discursive practices. Components of mathematical discourse are communication skills and mathematical vocabulary knowledge, both of which are important to fully understand advanced mathematics concepts. Researchers found that secondary students correctly explained mathematical concepts and ideas by using precise vocabulary after participating in STEM PBL activities (Bicer et al., 2015). The newly applied linguistic mastery becomes more richly embedded in students' language registry because they are acquired through practical and applied experiences shared among peers.

3.1.4. Retention in STEM Careers

There is a need for individuals to continue to pursue advanced STEM degrees and STEM-related careers. Researchers have shown that individuals with the mental flexibility to identify and consider multiple strategies and solutions during the problem-solving process have greater success in STEM academic and career pathways (Mayasari et al., 2015; Pinasa et al., 2017). Thinking more flexibly means embracing mistakes and discovering different methods when solving specific problems. In other words, creativity is necessary to be successful in STEM.

Perceptions of creativity in STEM are not universal and can in fact have indirect consequences on people's career pathways. Specifically, women's beliefs regarding creativity in STEM may influence whether or not they pursue a STEM career (Valenti et al., 2016). As such, understanding how STEM professionals view creativity's place within their field can help researchers and educators adapt and develop instructional practices in a way that increases the number of individuals pursuing a STEM-related career.

3.1.5. Learning Outside the School Building

Students can learn in formal settings, such as a typical school classroom or laboratory, and informal settings, such as summer camps and programs. STEM summer camps help students engage with STEM-related topics on a deeper level than typically available in formal learning settings. Furthermore, summer camps are often more focused on engaging students' curiosity and creativity by opening their eyes to the possibilities available in the STEM fields. Students in these camps also have the opportunity to embrace the mistakes they make when working on a STEM-focused project and realize how they can be creative in developing new solutions. In other words, STEM summer camps can effectively ignite and foster creativity in STEM.

It is important to consider the type of student who is likely to attend STEM summer camps and the activities in which they engage. Signing up to attend a summer camp involves a different level of interest regarding wanting to learn more about STEM concepts, as students who are more motivated about a topic have a higher interest level and are willing to invest time into learning (Csikszentmihalyi, 1975). Topics taught at STEM summer camps are also specialized and require deep initial interest, and students enroll in classes such as coding, bridge building, and 3-D printing, which enhance students' creative thinking skills by requiring them to design and create various products. Previous research indicates that informal settings, such as STEM summer camps, provide opportunities for students to become more aware of STEM-related career choices and degrees, which is important knowledge that is separate from and interreacts with STEM interest. This new awareness increases the likelihood that students would develop an interest in STEM and hopefully lead them to pursue and complete a STEM degree and ultimately select a STEM career (Cooper & Heaverlo, 2013).

In the current study, researchers used the following guiding research questions: 1. What effect does a STEM-focused summer camp have on students' attitudes towards creative problem-solving? 2. How does gender or grade level influence students' attitudes towards creative problem-solving?

3.2. Methods

The research team conducted a quasi-experimental design (e.g., Shadish et al., 2002) aimed to investigate the effects of a STEM summer camp on students' attitudes towards creative problem-solving. A single group pre/post design was used because it provides insights that can inform theory and determine if a relatively stable trait, such as creativity or attitudes toward creativity, can be influenced by activities and instructional pedagogy. There is no claim for causality nor any attempt at generalizability. The intervention occurred from June 16 to June 29, 2019, and July 7 to July 20, 2019, at a university in the southwestern United States. The summer camps had open enrollment, and participants explored various educational interests. For example, experiences offered during the STEM summer camp included coding, structures, and 3D printing courses and various lab tours (e.g., a physics show and a chemistry show). All experiences fostered connections to real-world applications and the encouragement of students to use creative problem-solving skills. The activities were open ended and required students to solve multiple problems to address all the aspects of the experience. The researcher team collected quantitative data and analyzed it to examine attitudes toward creative problem-solving.

3.2.1. Participants

There were 213 participants in the study and 114 participants completing both the pre- and post-surveys. There was a 46.5% attrition between the delivery of the pre- and post-surveys. Study participants ranged in age and spanned from the 6th to 12th grades, and all attended an open-enrollment STEM summer camp (see Table 3.1). Table 3.1 disaggregates the ethnicities of the total amount of participants overall and the those who have complete data. There were similar demographics between the students who completed all items and the full sample. The research team collected student data with parental consent and student assent.

Table 3.1 Demographics for Population and Sample

	Grade Level	*N* (%)	*n* (%)
Grade Level	6th	7 (3%)	3 (2%)
	7th	27 (13%)	20 (18%)
	8th	21 (10%)	11 (10%)
	9th	40 (19%)	20 (18%)
	10th	60 (28%)	29 (25%)
	11th	37 (17%)	17 (15%)
	12th	21 (10%)	14 (12%)
	Total	213	114
Ethnicity	American Indian	1 (0.5%)	1 (0.9%)
	Asian	27 (12.7%)	20 (17.5%)
	Black	16 (7.5%)	4 (3.5%)
	Hispanic	39 (18.3%)	20 (17.5%)
	Native Hawaiian	1 (0.5%)	0 (0.0%)
	White	102 (47.9%)	59 (51.8%)
	Mixed/Other	16 (7.5%)	3 (2.6%)
	Blank	11 (5.1%)	7 (6.2%)
	Total	213	114
Gender	Male	126 (59%)	64 (56%)
	Female	87 (41%)	50 (44%)
	Total	213	114

3.2.2. Intervention

The intervention consisted of students enrolling in STEM-related courses. There were 15 separate courses students could enroll in, and each course required students to work collaboratively to problem solve and develop a final project. A STEM professional guided each experience. Each course had class time for 1.3 hours each day for five days.

3.2.2.1. Summer Camp Learning Experiences

Students were given opportunities to develop and enhance critical-thinking and problem-solving skills through engaging in PBL activities focusing on specific STEM topics. Some examples of courses in which students could enroll include the following:

Renewable Energy/Hydroponics, Cryptography, 3D Printing, Drones, Microcontrollers, Coding, Structures, Chemistry, Advanced Coding, and Physics. During the course on Structures, students formed groups and built bridges with popsicle sticks using various constraints. The goal was a tripartite mission, and students could choose to compete in only one mission or all three. The missions were 1) to support the greatest amount of weight per gram of bridge mass, 2) to build the most realistic bridge, and 3) to build the most aesthetically pleasing bridge. Throughout the course, students became very involved in learning the engineering behind building bridges and wanted to win the competition, a motivation that encouraged creative thinking in different ways depending on the missions the students sought to complete. Overall, PBL activities in each of the courses gave students more autonomy in their learning and allowed them to better understand STEM-related topics.

3.2.3. Instrument and Data Analyses

Creativity and flexibility in thinking are important to complete creative problem-solving activities. As such, researchers wanted to measure the effect a PBL STEM camp environment that was designed to foster creativity and flexible thinking had on students' attitudes towards creative problem-solving. Researchers developed a 38-question ideation survey designed to measure students' perceptions about creative problem-solving. The survey used a scale with values from 0 (*strongly disagree*) to 100 (*strongly agree*). All students were administered the survey as a pre-survey on the first day of camp and as a post-survey on the last day of camp. The original target pilot results in a .79 reliability across all students.

Some students had multiple pretest or posttest responses. To resolve this, we used the response that was recorded with the later timestamp, as the participants may have realized they made a mistake and wanted to redo their responses. We used Stata 15.1 for the analysis. We first analyzed data using descriptive statistics, 95% confidence intervals (CI), paired-sample *t* tests, and Hedge's *g* effect size. Effect sizes quantify differences between groups (Coe, 2002), and using both effect sizes and confidence intervals allows for assessing the practical importance of the study without limitations of sample size or potential Type I or II errors.

Once the statistical and practical significance of the data were determined, we conducted a q-sort with the 38 survey questions. The q-sort allowed researchers to develop a parsimonious structure by creating factors of the 38 items. We asked three graduate students who range in their level of creativity traits (very creative, somewhat creative, not very creative) to group the questions together based on similarities. The level of creativity was determined based on activities and prior research conducted by the graduate students. The responses allowed us to group the 38 questions into six factors. We calculated the reliability of the factors, which resulted in four factors that exceeded the threshold of 0.70 and two with a Cronbach alpha of at least 0.55 (see Table 3.2).

Table 3.2 Factor Names, Alpha Scores, and Sample Items

Factor Names	Chron α	Sample Items
1. New Ideas Are Pointless	0.77	Listening to other people's ideas is a waste of time.
2. Collaborating Needs Structure	0.78	A group must be focused and on track to produce worthwhile ideas.
3. STEM Is Creative	0.83	I believe STEM (Science, Technology, Engineering, and Mathematics) courses and careers require a lot of creativity.
4. Collaboration Leads to Change	0.74	The best way to generate new ideas is to listen to others then tailgate or add on.
5. New Ideas Lead to Change	0.55	I really enjoy the challenge of finding a different way to solve a problem.
6. Creativity Is Chaos	0.59	Creative people generally seem to have scrambled minds.

Once we finalized our six factors, we conducted a MANOVA. Two groups of factors were highly correlated. Factors 1, 2, and 6 comprised one second-order factor, and factors 3, 4, and 5 comprised the other. We named the first higher order factor Time Efficiency. The underlying characteristic was that items subsumed in this factor dealt with the notion that discussing ideas is a waste of time and we could limit the number of extra discussions to achieve our goals more quickly. We named the other higher order factor Collaboration. The underlying characteristic was that items within this factor dealt with the idea that collaboration and discussion of new ideas is key to the success and progression of STEM.

3.3. Results

Researchers compared students' pre- and post-survey scores from the survey. The results of the paired-sample *t* test indicated that students who were part of a STEM summer camp had positive growth from presurvey (*M* = 2329.05, *SD* = 348.59) to postsurvey (*M* = 2468.28, *SD* = 397.17); specifically, there was an increase in their attitudes towards creative problem-solving ($t(113) = 3.63$, $p < .001$). The Hedge's *g* effect size was selected because it is a more conservative measure of the practical significance. The Hedge's *g* effect size ($g = 0.37$) and the 95% CI [0.11, 0.63] indicated a positive improvement in middle school and high school students' attitudes towards creative problem-solving with practical significance. Once statistical and practical significance was determined for the pre- and post-test data, researchers next reported on the statistical significance of the factors by gender and grade level.

We report the results from a higher order factor analysis (see Navruz et al., 2015) on the six factors from the q-sort. Factors 1, 2, and 6, or as we labeled them Time Efficiency, all had a common theme of limiting the amount of time used on discussion of ideas. The Wilk's Lambda for the MANOVA test on Time Efficiency is reported in Table 3. We found this was statistically significant ($Wilk's\ \Lambda = .85,\ F(3, 109) = 6.54, p < .001,$ multivariate $\eta^2 = .15$) for the overall model and the independent variable of gender. The multivariate η^2 = .22 indicated that about 22% of the variance was explained by gender and grade level for Time Efficiency. The multivariate η^2 = .15 indicates that about 15% of the variance is explained by gender for Time Efficiency (see Table 3.3).

Table 3.3 Time Efficiency MANOVA Results

Time Efficiency	Statistic	F	df	p	η^2
Model	0.778	4.85	2	< 0.001	0.22
Gender	0.848	6.54	1	< 0.001	0.15*
Grade Level	0.950	1.93	1	0.129	0.05*

Note: * indicates partial η^2

The second higher order factor, comprising factors 3. 4, and 5, all had a common theme of Collaboration as a key to progression and success of the STEM field (see Navruz et al., 2015). The Wilk's Lambda for the MANOVA test on Collaboration is reported in Table 4. We found this was statistically significant ($Wilk's\ \Lambda = .89,$ $F(3, 109) = 4.54,\ p < .01,$ multivariate $\eta^2 = .11.$) for the overall model and the independent variable of grade level. The multivariate η^2 = .13 indicated that about 13% of the variance is explained by gender and grade level for Collaboration. The Wilk's Lambda test is significant. This indicates there is a significant difference among gender and the factors 3, 4, and 5. The multivariate η^2 = 0.11 indicated that about 11% of the variance is explained by grade level for Collaboration (see Table 3.4).

Table 3.4 Collaboration MANOVA Results

Collaboration	Statistic	F	df	p	η^2
Model	0.88	2.50	2	< 0.05	0.13
Gender	0.10	0.88	1	0.412	0.02*
Grade Level	0.89	4.54	1	< .01	0.11*

Note: * indicates partial η^2

3.4. Discussion

Creativity is an elusive trait yet a highly sought after one. Chinese business and STEM students are sent to the United States, Canada, and the United Kingdom to learn creativity (Cheung, 2016; Martinsons, & Martinsons, 1996; Van Harpen, & Presmeg, 2013). Despite its importance, there is not a single study that links the learning of creativity to the teaching of mathematics in a creative manner. Perhaps this is because creativity is not like mathematics or science achievement, in which we can directly measure every construct or concept through a straight-forward and well-established process and measure how well someone can do something, directly teach the construct or concept under study, then measure how well they perform after instruction. Creativity is not that simple; it is more like attempting to measure love than any STEM concept. For this reason, many scholars have opined that creativity is more of a trait than a state, which is significant because traits are robust to change while states are more susceptible to modification.

When students experience carefully crafted instruction, their creativity, or at least their perceptions about creativity, can be influenced. Specifically, an open problem-solving structure, small group activities, and the guidance of STEM professionals seem to be the attributes of STEM PBL instruction that are the likely features responsible for the results. Creativity can be taught proximally alongside other subjects; it can be nurtured. In mathematics, creativity can be encouraged through engaging students in STEM PBL tenets (Capraro et al., 2013).

Mathematical creativity is a complex concept but one that can be achieved with effective enactment of carefully designed pedagogical approaches. Emphasizing creative thought and flexibility of thought will help students become more engaged and motivated in their learning of mathematics. Creative thinking, problem-solving skills, and critical-thinking skills acquired through PBL activities help students work toward a solution to a problem by considering the problem from different perspectives rather than by a set, memorized method. When STEM PBL activities are used effectively in classrooms or informal settings, students develop a deeper understanding of the concepts used and improve the problem-solving and critical-thinking skills they will require for future success.

Based on the current study, implementing STEM PBL activities into the formal classroom setting can help students improve their problem-solving skills. Students in the mathematics classroom can have low confidence in their problem-solving skills but encouraging exploration and autonomy in the students' own learning can increase their confidence towards mathematics. This study focuses on a STEM-specific camp, which is not the environment of a classroom, but incorporating PBLs into classroom lessons and reorganizing how a teacher presents the material can be beneficial for students. The findings of the study indicate that allowing time for students to explore their learning and take ownership will improve attitudes and hopefully lead to more students interested in the STEM field.

3.5. Conclusion

The primary purpose of the study was to understand students' attitudes towards creative problem-solving skills after exposure to a pedagogical approach designed to elicit creativity. Based on the findings of the current study, students who participated in a summer STEM camp had positive attitudes towards creative problem-solving. We found there was a statistical difference in gender when it pertained to time-efficiency but when analyzing collaboration, grade level showed a statistical difference. Taking a look into possible gender differences among secondary students could help to better implement creative pedagogical techniques. Encouraging students to get involved in learning through informal settings can improve their problem-solving skills and creative thinking. The hands-on and collaborative approach to learning enabled students to creatively problem solve. Problem-solving skills are important, and helping students find avenues to better their problem-solving skills can help improve their attitudes towards problem-solving. Using PBL in classrooms allows students to think more flexibly and creatively. Encouraging the use of PBL in the formal and informal settings increases positive attitudes, which is a goal in mathematics education.

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4. PRE-SERVICE TEACHERS BELIEFS ABOUT MATHEMATICS AND MATHEMATICS TEACHING

4.1. Introduction

Science, technology, engineering, and mathematics (STEM) degrees are becoming more necessary with further advancements and demands in careers that require STEM degrees. Mathematics, in particular, is becoming more and more important in today's technology-driven world and is also important within many STEM careers. Thus, it is especially important for mathematics teachers to possess positive beliefs in themselves about their own mathematics understanding and also be open to different pedagogies for learning various topics. Success as a 21st century teacher, in fact, comes from the ability to consider a problem and develop a variety of possible solutions until a final solution is found, and it is important to acknowledge that flexible thinking leads to better problem-solving skills. Teaching at any grade level can be difficult, but when a teacher possesses a negative outlook toward a specific subject, it can make teaching that subject much more difficult. Some of the most crucial learning in mathematics occurs while a student is in elementary school, so elementary mathematics teachers are very important in building students' mathematics foundations. Potential shortcomings at this stage can have long-lasting effects; incoming college students arrive with varied mathematics abilities (Tarver, 2015). Mathematics education courses should therefore devote more time to teaching strategies that help promote creative problem-solving skills, develop students' logical thinking skills, students' ability to analyze and think flexibly and use basic concepts to come to conclusions (Aladro & Ratner, 1997).

Negative mathematics beliefs increase as pre-service teachers (PSTs) go through their program (Mkhize & Maistery, 2017). Universities have an opportunity to correct their ways and instill confidence in their ability to teach mathematics education. One such strategy is encouraging creative thought which improves problem-solving and critical-thinking skills (Birgili, 2015). Pre-service teachers enrolled in education courses are for mathematics educators to convey how important of a role they play in helping their students improve problem-solving skills. This process begins with their own perceptions of mathematics.

4.1.1. Creativity, Motivation Towards Mathematics

Creative thinking plays an important role in STEM degrees. Creativity is the ability to generate novel ideas in a particular field and to come up with a variation in a domain (Csikszentmihalyi, 1999; McIntyre & McIntyre, 2007; Sriraman, 2004). Mathematics tends to be a subject that is typically considered as one with a specific process to solving a problem and no room for creativity (Schoenfeld, 1989). According to Torrance (1974), creative thought consists of four parts: fluency, flexibility, novelty, and elaboration, and is shown to contribute to academic success (Bentley, 1966). Creativity allows an individual to explore various strategies, or flexibility, in one's problem-solving and thought process to come up with solutions to a problem and/or concept (Bicer et al., 2018; Land, 2013). Flexible thinking helps with developing a more positive outlook on learning mathematical concepts. Creative thinking is an important process that can be practiced and developed with a positive relationship between academic achievement and retention (Epstein et al., 2008; Gajda et al., 2017; Shell et al., 2013). Creativity in mathematics is important and pre-service teachers who possess a deep mathematical understanding and the ability to see relationships between creativity and problem-solving are more successful in incorporating creativity into their teaching (Leikin et al., 2013). Introducing activities that motivate students and fostering creative thought increases the desire to continue perusing STEM degrees.

4.1.1.1. Pre-Service Teachers Flexible Thinking

A pre-service teachers' own mind can be his or her worst enemy and can dictate how he or she can or will perform or will perform in a class. These individuals can either believe that intelligence is fixed and unchangeable or that intelligence is dynamic and changeable (Shell et al., 2013). According to Matthews and Foster (2005), there has been a shift in paradigm called the mystery and mastery model of giftedness. The idea of the model is to explain the shift in mindset from a static, once intelligent, always intelligent, focus to a more dynamic, intelligence comes from practice and effort, focus. Students who believe intelligence is changing tend to set learning goals, engage in better self-regulation, and achieve more (Shell et al., 2013). Students who are more engaged in a subject tend to perform better and have a more positive feeling towards learning (Pekrun & Linnenbrink-Garcia, 2012; Shell & Husman, 2008; Shell & Soh, 2013). The mastery model aligns with the idea of thinking more flexibly and the idea of embracing mistakes to help further learning and understanding. Studies show that individuals with the mental flexibility in identifying a variety of strategies and solutions to a problem have greater success in STEM-related degrees and careers (Mayasari et al., 2017). Pre-service teachers who think more flexibly embrace mistakes and discover different methods when solving problems. Self-confidence in mathematics skills can be acquired by the using techniques such as collaborative learning and focusing on how abilities can be improved (Aladro & Ratner, 1997; Shell et al., 2013). Gaining self-confidence in one's own ability can further their own mathematical understanding and lead to creative teaching.

4.1.1.2. Importance of Motivation

A pre-service teachers' perception of ability, or self-efficacy, dictates if they will be more creative in how they solve problems and eventually teach their future students. Self-efficacy is an individual's belief in his or her ability and effort put in to be successful in a specific area (Bandura, 1977). Pre-service teachers who believe in their ability to learn a concept tend to persist longer, believe they will be successful in the future, and take control over their learning leading to autonomy (Wigfield & Wentzel, 2007) leading to more interest in their learning and more confidence to think creatively. Motivation, both intrinsic and extrinsic, are associated with one's self-efficacy and interest in completing a specific task (Perez et al., 2014; Wigfield & Cambria, 2010). Intrinsic motivation comes from interest in the subject and show more positive coping mechanisms, where extrinsic motivation comes from knowing there will be an outcome, positive or negative, and show more tendency to blame others for mistakes (Ryan & Deci, 2000). Motivation, especially intrinsic, is essential to creativity (Sternberg, 2006). Motivation can be enhanced by valuing growth and effort in learning rather than on the performance or grade (Wilkie & Sullivan, 2018). Encouraging pre-service teachers to motivate themselves to succeed will improve their attitudes towards mathematics leading to eventual creative teaching. When students are motivated and interested in topics, they are generally willing to put in the extra effort to think more creatively (Ryan & Deci, 2000). Lowering negative beliefs towards mathematics in elementary and middle school pre-service teachers should lead to more students enjoying mathematics and ultimately pursuing a degree and career in the field. Placing more emphasis on the positive aspect of learning mathematics can help pre-service teachers be successful, as well as their future students (Kolstad & Hughes, 1994). The current study was guided by the following research question: How does engaging in creative problem-solving teaching strategies affect pre-service teachers' beliefs towards mathematics and mathematics teaching?

4.2. Methodology

This study was a concurrent mixed-methods (MMR) (Onwuegbuzie, 2002; Plano et al., 2016) design. Concurrent MMR is also referred to as convergent design where the researcher collects and analyzes quantitative and qualitative data then merges the two to compare or combine the results (Creswell & Plano Clark, 2018). Researchers collected quantitative data through the pre- and post-survey, as well as qualitatively analyzing open-ended questions. The primary purpose of this study was to understand how incorporating creative problem-solving techniques in a university level course can influence a pre-service teacher's (PST) beliefs towards mathematics and mathematics teaching. Each semester, at a university in the Southwestern United States, a problem-solving course is taught to PSTs seeking certification in elementary or middle school education. This course is typically taken during the second or third year of a four-year program of study leading to elementary or middle school teaching certification. One goal of the course was to increase PSTs' confidence in their own mathematical problem-solving skills to better prepare them to become effective future teachers.

In the Fall 2019 semester, the course was taught by two researchers who received Instructional Review Board (IRB) approval and explained the difference between participating in the study and not participating in the study. To account for potential bias, a third-party individual explained the instructions and distributed the pre survey and post survey while the instructors were outside the classroom. Pre-service teachers were informed that participation in this study would not affect their final grade, and participation was optional. If the student voluntarily answered the pre- and post-surveys, their data were included. Pre-service teachers were given 30 minutes on the first day and the last day of classes to complete the survey.

4.2.1. Participants

The participants consisted of a convenience sample of 46 elementary and middle-school PSTs who were enrolled in a problem-solving course during the Fall 2019 semester. All participants identified as female with half of the participants being in their junior year, 28% in their sophomore year, and 22% in their senior year (see Table 4.1).

Table 4.1 Demographics

		n (%)
Gender	Female	46 (100%)
	Total	46
Classification	Sophomore	13 (28.26%)
	Junior	23 (50.00%)
	Senior	10 (21.74%)
	Total	46

This group of PSTs were chosen because they were preparing to be certified to teach mathematics to students in kindergarten to 8th grade. Additionally, they were chosen because the age group these PSTs will one day teach, are a crucial time in the students' learning of mathematics.

4.2.2. Instrument

The *Revised Shortened Version of the Mathematics Beliefs Scale Survey* (Capraro, 2001) was administered to PSTs on the first and last day of class (see Appendix A). The original survey (Fennema et al., 1990) was the basis for the Revised Shortened Version of the Mathematics Beliefs Scale. This scale was shortened to a more parsimonious one through a factor analysis because participants of the Capraro (2001) study stated the 48 items in the survey were repetitive and lengthy. Based on the data collected in a previous study (Capraro, 2001), the coefficient-alpha reliability was .68, and according to Shavelson (1988) this is marginally acceptable. The PSTs beliefs about mathematics and mathematics teaching were measured using the survey which consisted of 18 items broken into three factors: 1. Student Learning, 2. Stages of Learning, and 3. Teacher Practices. Six open ended survey questions (see Appendix B) were included following the Beliefs Scale to unpack these three factors and each question was aligned to one of the three factors on the Beliefs Scale. Pre-service teachers rated each of the 18 items on a 5-point Likert scale (1 strongly agree to 5 strongly disagree).

4.2.3. Intervention

The intervention was implemented for one semester in Fall 2019. Pre-service teachers enrolled in the course and met multiple days a week for the duration of the semester. During each class meeting, PST's were engaged in activities focused on researched-based pedagogical practices related to teaching elementary and middle school students the skills necessary for effectively teaching mathematical problem-solving. The lessons included effective pedagogical methods for incorporating creative thinking, 21st century skills and problem-posing skills into mathematics lessons. Topics focused on content necessary for PSTs to effectively teach problem-solving skills to their future students as well as engaging them in pedagogical strategies for teaching problem-solving.

Throughout the semester various learning objectives were covered. The learning objectives for the course included: Polya's four steps, number representations of quantity in terms of place value and units, one-step, two-step, and three-step problems involving the four operations: addition subtraction, multiplication, and division, and the mixing of operations within word problems. Pre-service teachers were involved in various instructional strategies including: collaboration, use of manipulatives, problem-posing, divergent thinking activities to encourage flexible thinking, and the incorporation of technology when appropriate. Throughout the lessons, PSTs were exposed to creative problem-solving techniques that were designed to help strengthen their content and pedagogical knowledge of mathematics. Instructors of the course modeled effective strategies PSTs can implement in their own classrooms.

To add the pedagogical aspect to the course, the instructors helped model methods of thinking flexibly by encouraging discussion among the PSTs. The instructors of the course allowed for mistakes to be made, and if a mistake was made during the lesson, the instructor used the opportunity as an example of how to not allow mistakes to cause discouragement. Pre-service teachers were given the opportunity to create their own word problems, which allowed for creative thinking skills to occur. At the beginning or ending of the class meetings, there was a reflection aspect on how they would implement creative problem-solving techniques in their future classrooms and a reflection of their beliefs of their own abilities. The reflection aspect is important for the PSTs to allow deeper thinking about the strategies and how they could see possibly enacting these in their own classroom.

4.2.4. Data Analysis

Data collected from the close-ended Likert-scale survey were analyzed using a paired sample *t*-test in STATA and by calculating the means, standard deviation (SD), effect size, and confidence intervals (CI) of the PSTs responses both before and after the intervention. One participant did not complete the pre-survey, but to account for their scores, researchers imputed the missing data.

The open-ended responses were analyzed using a constant comparative qualitative strategy to identify common themes from the PSTs (Olson et al., 2016). Data were then coded and categorized individually and then categorized into themes. Coding discrepancies were resolved until there was a 100% agreement (Olson et al., 2016).

4.3. Results

The pre-survey and post-surveys were analyzed both quantitatively and qualitatively. Due to the fact the Likert scale was arranged with 1 being strongly agree and 5 being strongly disagree, a decrease in mean indicated a positive change. The results from the paired sample *t*-test indicated PSTs had a positive growth in their beliefs towards mathematics and mathematics teaching after being involved in a problem-solving course (M = 40.21, SD = 8.18, $t(45) = 2.29$ $p<0.05$). To determine if there was an overall practical significance, the more conservative Hedge's *g* was calculated and indicated there was a moderate practical significance ($g = 0.44$, 95% CI [0.3, 0.85]) for PSTs who were involved in the problem-solving course. These results help indicate that being involved in a problem-solving course with the idea of a growth mindset, is beneficial to their overall beliefs in their own mathematical and teaching ability.

4.3.1. Stages of Learning

Each of the three factors (Student Learning, Teaching Practices, and Stages of Learning) were quantitatively analyzed with only one category showing a statistically significant change. The category, Stages of Learning, indicated a statistically significant increase from pre-survey (M = 14.24, SD = 3.58) to post-survey (M = 12.43, SD = 3.56, $t(45) = 2.77$ $p < 0.01$). Some Likert-scale questions connected to this factor included "Teachers should allow children to figure out their own ways to solve simple word problems" and "Mathematics should be presented to children in such a way that they can discover relationships for themselves". A Hedge's g effect size was calculated on Stages of Learning and there was a moderate practical significance ($g = 0.50$, 95% CI [0.09, 0.92]) which indicated PSTs who were involved in a problem-solving course did view stages of learning as important to the understanding and teaching of mathematics. To further understand this factor, PSTs responded to the open-ended question "What types of instructional strategies do you plan to use to facilitate and ensure learning takes place within problem-solving?". One response stated, "I want more than anything to create a safe, comfortable environment where the students feel safe to learn and be themselves". Another PST commented, "It will be necessary to allow them [my students] to dive in and learn and grow in their math skills". Common comments included using discussions in the classroom to help enhance the problem-solving learning environment as well as teaching a variety of techniques to help all of their students be successful. Allowing for flexibility in thinking and problem-solving, while creating the environment that mistakes are part of learning shows a positive increase in beliefs and understanding of teaching mathematics.

4.4. Conclusion

Properly preparing PSTs in mathematics and mathematics teaching is crucial for the future of STEM related careers. When elementary and middle grades PSTs are asked their thoughts on mathematics and mathematics teaching, there is majority who say they either do not feel comfortable with the subject or outright dislike the subject. The findings of this study show that when PSTs who are in a problem-solving course that encourages creativity and flexible thinking, they are more likely to have positive beliefs towards mathematics and mathematics teaching. Confidence in one's ability to understand and teach a subject is important when working with elementary and middle school aged students. Shifting the idea of mathematics being a static, "one method only", subject to more of a creative subject can lead to more interest in STEM fields.

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5. CONCLUSIONS

The main focus of this dissertation was to explore how creative problem-solving techniques influence students' attitudes, beliefs, and understanding about mathematics. The three studies each examine a specific group of students. The general findings of the three empirical studies indicate utilizing creative problem-solving techniques positively improved the students' mathematical attitudes, beliefs, and understanding among students of all ages that were participants in my three studies.

The decision behind examining primary, secondary, and post-secondary level students was because each time frame is an important period in learning mathematics. Figure 5.1 illustrates the cyclic representation behind choosing three different levels of students. This figure represents the beliefs held by PSTs' who are working toward certification to teach mathematics to K-12 students' can have an influence on the

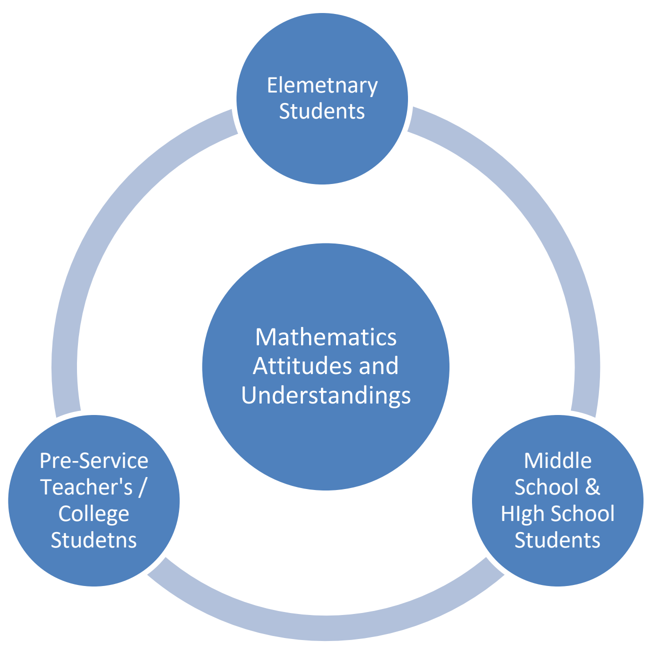

Figure 5.1 Cyclic Representation of Study Participants

elementary and middle school students' beliefs (Ramirez, et al., 2018) that they will teach in the future.

Intellectual Merit: The experience of learning mathematics starting from primary school is important in the development of confidence and viewpoints of mathematics. The way a student perceives their own mathematics ability in primary and secondary school can influence their attitudes as they study to become future teachers. The experience that pre-service teachers have in their elementary and secondary mathematics classes will impact their future teaching skills. Universities have a chance to mold the attitudes of future teachers and instill confidence in their abilities to teach mathematics in the future when they are certified and in charge of their own classrooms. Teachers are in an influential position and have the ability to affect the outcomes of their students; the more positive and enjoyable the classroom environment, the more students will be able to achieve (Kiwanuka et al., 2017). Shifting mindsets beginning in early education can lead to more positive attitudes towards mathematics.

Broader Impacts: The overall research findings resulting from this dissertation study provide important mathematics educational implications. One goal of mathematics educators is to lower negative beliefs associated with mathematics and increase positive beliefs and understandings among all people. Incorporating creative problem-solving activities into both formal and informal settings is attainable and can lead to more interesting and motivational ways to teach and learn mathematics.

Reflections on the Three Studies: The findings from the first study help enhance the current literature (Chang et al., 2011; Sugito et al., 2017; Sung et al., 2016) associated with the benefits of problem-posing activities. Students' mathematics identity can be shaped by their experiences in elementary school. My findings, in regard to elementary students' ability to pose solvable problems, did show there was a positive change in elementary students' mathematical understandings. Developing flexibility in thinking about mathematics problem and having students create solvable word problems is one of the benefits of including creative problem-posing activities in the mathematics classroom. Giving students the opportunity to create their own problems and write about context that interest them, led to more motivated students interested in learning and at times led to more complex problems being posed.

When considering mathematics education and the learning of mathematics content, the typical setting is within a formal classroom with very rigid methods employed by teachers to help students learn content. This rigidity is usually attributable to preparation for high-stakes testing. The findings in the second study help disprove the idea that learning mathematics can only occur in formal settings. Involvement in a STEM focused summer camp or any type of informal setting allows for more exploration into the content while providing students more freedom to learn without the constraints of high stakes testing. Incorporating PBL into mathematics teaching leads to a more positive outlook and improved attitudes towards mathematics. The findings of study two help with enhancing students' interest and hopefully lead to more interest in pursuing STEM related careers.

The findings in the third study allowed PSTs to participate and view what it means to explain mathematics content more flexibly. Study three examined PSTs while in a problem-solving course. Results showed an improvement in their own beliefs in mathematics and how they plan on teaching mathematics. Moving from rigid explanations about concepts to more flexible explanations, allowing for various representations, can lead to more confidence in PSTs, which can lead to confidence when teaching their future students. Incorporating activities that encourage creative thinking, no matter the setting offers opportunities for growth in mathematical understanding and comprehension.

Thus, through my three-article dissertation I have shown that enhancing students' self-beliefs in their own mathematical knowledge while engaging in creative problem-solving can make a difference in the learning of mathematics. One goal of mathematics educators is for students to have more positive self-beliefs about the subject and help their students recognize they are capable of understanding mathematics and being successful in a mathematics setting. There is still more to research on methods to help increase students' interest in mathematics and pursuing STEM fields, but the findings from the three studies about three different age demographics demonstrate using creative problem-solving techniques in a formal or informal setting leads to better comprehension of mathematics topics and attitudes.

Although there is valuable information from these studies, there are some limitations that could have affected the outcomes. Within the first study, a limitation of the study was the time frame of the intervention. The intervention occurred over one ten-week period and the activities were delivered by PSTs who could have unintentionally influenced outcomes. Another limitation of the study was the two grades involved were only second and fourth, and there were a small amount representing each grade level. With regards to the second study, limitations are the STEM camp was open enrollment and the students most likely chose to attend the camp. The camp itself was only a week or two weeks long in duration, not allowing for much time between the administering of the pre-and post-surveys. Finally, the third study's intervention was taught by the researcher, and though the students were informed the participation in the study was optional, there could have been a pressure to be involved. As for the sample, they were all females and required to take this course as part of their graduation requirements. Another limitation for all three studies was due to the various definitions of creativity, students may have had different perceptions of what constituted creativity, hence altering their responses. For future research, the instructors of the experiences that occur during the camp or within a classroom, could more explicitly explain the connection of creativity and what it means to be creative in a mathematics context.

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APPENDIX A

APPENDIX A REVISED SHORTENED VERSION OF THE MATHEMATICS BELIEFS SCALES

UIN:__________________________ Highest Level of High School Mathematics Taken:______________________________

Rate the following questions from 1 (Strongly Agree) to 5 (Strongly Disagree)					
Question	1 Strongly Agree	2 Agree	3 Undecided	4 Disagree	5 Strongly Disagree
Student Learning					
1. Recall of number facts should precede the development of an understanding of the related operation (addition, subtraction, multiplication, or division).					
2. Children will not understand an operation (addition, subtraction, multiplication, or division) until they have mastered some of the relevant number facts.					
3. Time should be spent practicing computational procedures before children are expected to understand the procedures.					
4. Children should not solve simple word problems until they have mastered some number facts.					
5. Time should be spent practicing computational procedures before children spend much time solving problems.					
6. Children should master computational procedures before they are expected to understand how those procedures work.					

Teacher Practices					
7. Most young children have to be shown how to solve simple word problems.					
8. Children should understand computational procedures before they master them.					
9. Children learn math best by attending to the teacher's explanations.					
10. Most young children can figure out a way to solve many mathematics problems without any adult help.					
11. To be successful in mathematics, a child must be a good listener.					
12. Children need explicit instruction on how to solve word problems.					

Stages of Learning					
13. Teachers should encourage children to find their own solutions to math problems even if they are inefficient					
14. Teachers should teach exact procedures for solving word problems.					
15. Mathematics should be presented to children in such a way that they can discover relationships for themselves.					
16. The goals of instruction in mathematics are best achieved when students find their own methods for solving problems.					
17. Teachers should allow children who are having difficulty solving a word problem to continue to try to find a solution.					
18. Teachers should allow children to figure out their own ways to solve simple word problems					

APPENDIX B

APPENDIX B OPEN ENDED QUESTIONS

Please answer the following questions.

1. (Student Learning) Reflect back on when you were in mathematics class during elementary/middle school. Did your teacher allow for multiple representations or methods of solving a problem? Explain your answers.

   ____
   ____
   ____
   ____
   ____

2. (Student Learning) Reflect back on when you were in mathematics class during elementary/middle school. Did you engage in any hand-on learning experience/ activities when solving a problem? Explain your answers.

   ____
   ____
   ____
   ____
   ____

3. (Teacher Practices) When you are teaching in your own classroom, how will you want your students to solve word problems?

4. (Teacher Practices) When you are teaching in your own classroom, will you use hands-on activities for students to solve problems? This sounds like a yes or no answer

5. (Teacher Practices) How do you think the hands-on learning experience will enhance students' problem-solving skills and their beliefs about problem-solving?

6. (Stages of Learning) What types of instructional strategies do you plan to use to facilitate and ensure learning takes place within problem-solving?