Fall 12-2021

Investigating the Effects of Problem-Posing on High School Students' Mathematical Learning

Min Wang
minwang@smu.edu

Investigating the Effects of Problem-Posing on

High School Students' Mathematical Learning

by

Min Wang

A Dissertation Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

Department of Teaching and Learning

Southern Methodist University

November 2021

Abstract

Problem-posing activities have received more attention in mathematics education in recent decades. Problem-posing activities' effects on improving students' mathematical learning have been studied by extant studies. This study implemented an explanatory sequential mixed-method research design to investigate the impact of problem-posing activities in the walkSTEM program on high school students' mathematical outcomes. The researcher analyzed students' problem-posing work and compared the content complexity levels of student-generated problems in different activities. The result suggested that students posed the more complex problems in the Final Walk project and they also posed more complex problems in the post-survey compared to the pre-survey. Students' responses in the pre- and post-survey were investigated along with the post-intervention interviews. There was no statistically significant difference between students' mathematical interest in the pre- and post-survey. The qualitative analyses revealed that students started to think more, think deeper, ask more questions, and connect topics and content they learned about at school to everyday objects and real-life scenarios. The researcher also explored the relations among students' problem-posing skills, problem-solving skills, mathematical dispositions, conceptual understanding, and procedural fluency. According to the findings, problem-posing performance was positively correlated to students' mathematical interest and problem-solving skills, and conceptual understanding was a significant predictor for students' problem-posing performance. The online meeting recordings were analyzed qualitatively to identify instructors' scaffold strategies to support students' problem-posing. Scaffold strategies identified from the recordings were: modeling problem-posing, providing feedback to student-generated problems, and utilizing education technology to enhance students' participation level. In conclusion, this study validated problem-posing's positive effects in improving problem-

posing skills and mathematical dispositions, and helping students connect school mathematics to real-world applications. The study also compared students' performance and preferences in different types of problem-posing tasks and future research could investigate how to better incorporate and scaffold these tasks in problem-posing programs.

Keywords: problem-posing, mathematics education, high school, mixed-method.

Table of Contents

Chapter 1: Introduction

Problem-posing activities have received more attention in mathematics education both in the United States (English, 1997, 1998; Walkington, 2017; Walkington & Hayata, 2017) and in other countries including China (Chen, Van Dooren, Chen, & Verschaffel, 2007; Li & Lü, 2004), Singapore (Cai, 2003), Indonesia (Suarsana, Lestari, & Mertasari, 2019), and Turkey (Ozdemir & Sahal, 2018; Salman, 2012). Researchers also conducted cross-national studies on problem-posing to explore the mathematical achievement differences between students of different countries (Cai, 1998; Cai & Hwang, 2002; Cai & Jiang, 2017).

Problem-posing "is a feature of broad-based, inquiry-oriented approaches to education" (Silver, 1994, p.21). In the literature, problem-posing has been described as follows: "Problem-posing refers to both the generation of new problems and the re-formulation, of given problems. Thus, posing can occur before, during, or after the solution of a problem" (Silver, 1994, p.19). Students can imbed their prior knowledge, interests, and background into the problem-posing process. Previous research shows that most students have limited prior experience in posing mathematical problems before participating in problem-posing interventions. However, across studies that evaluated problem-posing performance, there was no apparent floor effect. In other words, most students could successfully pose correct and meaningful mathematical problems (Cai, 1998; Cai & Hwang, 2002; Chen et al., 2013; Chang et al., 2012; Zakaria & Ngah, 2011). In Walkington and Hayata (2017), the authors introduced problem-posing activities in a teaching experiment. They discussed how students could generate mathematical problems in real-world contexts and draw upon their funds of knowledge (Moll, Amanti, Neff, & Gonzalez, 1992). Moll et al. (1992, p.134) defined funds of knowledge as "historically accumulated and culturally

developed bodies of knowledge and skills essential for household or individual functioning and wellbeing".

When students are engaged in problem-posing activities, they become active learners instead of passive receivers (Ellerton, 2013), making it possible for educators to utilize problem-posing as an effective formative assessment tool. In Dominguez (2016), the author described the students' problem-posing process as a "windows-and-mirrors framework for investigating student noticing"(p. 360). In Lin and Leng (2008), the authors evaluated 120 advanced students' problem-posing work and concluded that students demonstrated "what they know and what they can do with their mathematical knowledge" through the problem-posing tasks (p. 1).

Problem-posing activities empower students to see mathematical topics from new perspectives, gain deeper understandings, make connections between real-world scenarios and mathematical concepts, and self-monitor or self-regulate their cognitive processes (Brown & Walter, 1990). These characteristics align with the Standards for Mathematical Practice in the Common Core State Standards for Mathematics (CCSSM): students should make sense of the problems, construct viable arguments, choose the appropriate tools to solve the problems, and model everyday life scenarios mathematically. Additionally, extant studies suggested that integrating problem-posing in students' mathematical learning can positively impact students' problem-solving skills, problem-posing skills, conceptual understanding, and dispositions toward mathematics. These positive learning outcomes fall under the five strands of mathematics proficiency listed in National Research Council (2001): conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition.

This study investigated the problem-posing activities in the walkSTEM program. walkSTEM is an initiative in a large southwest metropolitan area where students, classes, and

families take walks and find mathematical concepts and principles in the architecture, art, and nature around them. The Create Your Own walkSTEM initiative is a group of clubs where students make "stops" on a walk around their schools, leading their audience on the walk and explaining how mathematics is integrated into the surroundings. Since this study was implemented during a pandemic, the walkSTEM program was modified into an online program. Students met with the instructors and other program members online to watch walkSTEM videos made by previous club members and design their own online walkSTEM walks collaboratively.

Due to the broad definition of problem-posing learning activities, the problem-posing tasks in extant studies vary significantly. This variability makes it difficult for classroom teachers, school administrators, and researchers to learn about the whole picture of problem-posing or to select a problem-posing intervention that would be most effective and appropriate for their students. Additionally, even though problem-posing's positive effects on students' mathematical learning has been examined in extant literatures, most of the educators have limited experience with implementing problem-posing with their students. Therefore, it is important to investigate the effective scaffolding strategies to support students' problem-posing. Moreover, this study implemented a completely online problem-posing program, which is different from any prior problem-posing interventions. There were studies included web-based problem-posing activities or modules in the in-person interventions to better support students' problem-posing and enrich students' experience in the interventions (Chang et al., 2012; Suarsana et al., 2019). Despite of the online component, teachers in these studies still relied on in-person class meetings to implement the problem-posing interventions. Given that remote learning has become more prevalent these days, this study explored the possibility of online

problem-posing instruction and investigated both the advantages and challenges of implementing problem-posing through virtual schooling.

Therefore, this study aimed to (a) investigate the relations among students' problem-posing skills, problem-solving skills; mathematical dispositions, conceptual understanding, and procedural fluency; (b) explore students' problem-posing performance while participating in the problem-posing activities in the walkSTEM program: (c) explore the scaffolding strategies instructors implemented during the walkSTEM program.

Chapter 2: Literature Review

I conducted a literature review to provide a systematic review of literature on problem-posing interventions implemented with grade 1-12 students. This review focuses on the theoretical frameworks relevant to the relation between problem-posing and problem-solving in mathematics education and summarized the characteristics of problem-posing activities implemented in the extant literature, scaffolding provided for students, problem-posing's effects on students' mathematical academic outcomes.

Theoretical Framework

This section first introduces the different types of problem-posing tasks and some scaffolding strategies to support students' problem-posing in extant literature. Followed by the introduction, this section presents the current theory and literature discussing problem-posing and problem-solving activities in mathematical learning. The positive effects of these two learning activities were both examined and revealed in extant literature. Given the close relation between problem-posing and problem-solving, the author emphasizes the theoretical perspectives that explain this connection and summarize results in extant literature that compared problem-posing with problem-solving activities' effects on students' mathematical learning outcomes.

Problem-Posing Activities' Characteristics

As defined earlier in the introduction section, problem-posing activities could vary drastically due to its broad definition. With respect to the structure problem-posing tasks, Stoyanova (2003) categorized problem-posing situations into free problem-posing, semi-structured problem-posing, and structured problem-posing. In structured problem-posing tasks, students re-formulated given problems or generated problems based on a specific solution. In semi-structured problem-posing tasks, students generated problems based on a given problem structure or solution structure. Free problem-posing tasks refer to posing problems for the formation of a mathematical operation, problem-posing tasks that involve using a particular solution method, and problem-posing situations in which there is no specification of which type of problem to pose or which area the problem should be based on. Examples of free, semi-structured, and structured problem-posing tasks are presented in Table 1.

Table 1

Examples of Free, Semi-Structured, and Structured Problem-Posing Activities According to Stoyanova (2003)

Problem-Posing Type	Problem-Posing Activities Examples
Free	• The teacher informs the students, "I am going to write a few words/ numbers on the whiteboard which are considered to be the starting words/numbers of a potential problem to be solved. Afterward, each time I will choose one of you to come to the whiteboard to add at most two words/numbers next to the previous words/numbers to form consistent and fluent expressions for a potential problem."
Semi-Structured	• Students are asked to pose problems in a given range and type them into the system. They type in the content of their problems and the correct answers. • Problems with surplus or insufficient information were also used in these activities. For instance, students were given an open statement: "Consider that you have 3 railways from Ankara to Eskişehir". They were asked to complete the statement to pose a problem.

Structured	- Students were given the question: Find the different selections of 4 mathematics books among 9 mathematics books. One of the reformulations of this question was "How many different 4 mathematics books can be selected among 9 mathematics books?". - In the activities including the "what if not" strategy (Brown and Walter, 1983, 1993), students listed all attributes of a given problem, and then they had to ask "what if not attribute".

As students mostly have limited knowledge or experience in mathematical problem-posing, the scaffoldings students received are important to support successful problem-posing. Peer interaction scaffolding strategy was one of the most mentioned and investigated scaffolding strategies in the extant literature. Kontorovich, Koichu, Leikin, and Berman (2012) proposed a framework to analyze students' problem-posing process that includes five aspects: individual consideration of aptness which represents the interpretations of explicit and implicit requirements of a problem-posing task; task organization which includes the didactical decisions that a teacher makes when planning a problem-posing activity; knowledge base which includes the mathematical facts, definitions, prototypical problems, and competences of mathematical discourse and writing; heuristic and schemes which represent the generalized and decontextualized pieces of experience of problem posers; and group dynamics and interactions that include the processes of social nature that occurs when a group works on a problem-posing task together.

In Gade and Blomqvist (2015), the authors analyzed students' problem-posing process when they generated number-related and societal experience related questions and students would work together to pose problems to each other and reflect upon the problems posed by their peers. The authors suggested that students would challenge and counter-challenge each other in this process which was evidence of students' self-regulation, volition, and independence. Moreover, in Kitchings (2014), the author investigated students' problem posing that happened

when teachers engaged students in discourse and concluded that all problem-posing instances in the study occurred when students interacted with each other.

The Relation Between Problem-Posing and Problem-Solving

Unlike other mathematical learning activities, problem-posing usually does not exist independently but goes hand-in-hand with problem-solving in mathematics classrooms to meaningfully engage students in high-cognitive demand learning tasks. Students were guided to not only pose but also solve the generated problems (Chang et al., 2012; Cotič & Zuljan, 2009; Walkington, 2017; Xia, Lü, & Wang, 2008). The relation between problem-posing and problem-solving has been studied in the extant literature, and the researchers indicated that students with stronger problem-posing skills also tend to be stronger problem-solvers, and vice versa (Cai, 1998; K.-E. Chang et al., 2012; Chen, Van Dooren, & Verschaffel, 2013).

Problem-posing can occur before, during, or after a problem-solving task (Silver, 1994). One typical instance of posing mathematical problems before and during problem-solving activity is the process of re-formulating a given problem to approach the problem from different perspectives or break down the problem into less complicated solvable pieces. Extant research that investigated how experts and novices in mathematics address complex tasks differently indicated that experts spent considerably more time formulating and re-formulating the problems than novices (Silver & Marshall, 1990, as cited in Silver, 1994, p. 20). Another widely used problem-posing task is to ask students to generate new mathematical problems after solving a given problem. According to the specific instructions of the problem-posing tasks, students might pose a similar mathematical problem in a different scenario, pose a different problem with the same solution, or generally pose any mathematically meaningful problems related to the solved problem.

The reciprocal relation between problem-posing and problem-solving has been discussed in extant literature (Cai, 1998; Chang et al., 2012; Chen et al., 2013). For instance, in Silver and Cai (1996), the authors conducted an exploratory study with middle school students. They concluded that stronger problem-solving skills were associated with stronger problem-posing skills, which means the posed problems were more complicated and insightful. However, there are also study findings revealing students with lower problem-solving performance could outperform their peers with higher problem-solving performance in problem-posing in some perspectives. For instance, in Cai and Hwang (2002), the author revealed that even though Chinese students outperformed U.S. students in problem-solving, the types of problems and the overall distribution of the problem types posed by Chinese and U.S. students were similar. And the U.S. students were even more likely to pose extension problems than the Chinese students. Students were given a finding pattern problem with three figures and they were asked to come up with problems according to this pattern. The extension problems referred to problems questioning the pattern beyond the given figures, and posing extension problems were associated with greater problem-solving success according to Cai (1998).

Why Does Problem-Posing Improve Problem-Solving Skills?

Theoretical explanations of why problem-posing activities can improve students' problem-posing skills focuses on the relations amongst problem-solving, students' metacognitive skills, and dispositions toward mathematics, problem-posing's effect in increasing students' engagement in learning mathematics, helping students' to develop understanding about mathematical concepts, and providing students opportunities to understand the problem structures.

In Mayer (1998), the author examined the roles of cognitive (skills), metacognitive (meta-skills), and motivational (will) skills in problem-solving and suggested that students need to acquire all three kinds of skills for successful problem-solving. In this study, cognitive skills include procedural knowledge, instructional objectives, and the components in information processing (i.e., encoding, inferring, applying, and responding). Metacognitive skills involve the knowledge of when to implement the various skills students have learned and how to coordinate and monitor the skills. Motivational skills mainly focus on students' motivation in solving the problems based on interest, self-efficacy, and attributions.

Problem-posing learning activities promote both students' metacognitive skills (Karnaina, Bakara, Siamakania, Mohammadikiaa, & Candrab, 2014) and their attitudes and interests toward mathematics (Silver, 1994; Walkington, 2017). Specifically, suppose students are given a mathematical problem and are required to generate some similar problems. In that case, they need first to analyze the problem holistically (Silver, 1994) and understand the dynamics of the given problem (Priest, 2009) before they start to generate their problems. After posing the problems, students also need to develop a more thorough understanding of the logical relation amongst the problem texts, the question sentences, and the solutions to the problems they posed (Arikan & Ünal, 2015; Cai, 1998; Cankoy & Darbaz, 2010; English, 1997; Kopparla et al., 2019; Priest, 2009). During these processes, students constantly self-monitor and self-regulate their problem-posing procedures, thereby improving their metacognitive skills. Regarding problem-posing's positive impact on students' motivational skills, extant literature had discussed how students' engagement with problem-posing could stimulate students' interest in mathematics learning and reduce students' mathematics anxiety which includes syndrome of

fear and avoidance towards learning mathematics (Brown & Walter, 1990; Silver, 1994; Singer, Ellerton, & Cai, 2013).

Given the evidence in previous studies that problem-posing activities are associated with students' growth in metacognitive and motivational skills, this theory proposes one theoretical explanation that problem-posing's positive effect on problem-solving performance is mediated by improving students' metacognitive and motivational skills.

Additionally, there are other theoretical explanations about problem-posing's positive effects on problem-solving: problem-posing activities can provide students' opportunities to develop deeper understanding of the mathematical concepts, the structure of the problems and solutions, and problem-posing creates a natural way to connect school mathematics curriculum with real-world scenarios. For instance, Mahendra et al. (2007) examined students' conceptual understanding after participating in a problem-posing intervention and identified a positive effect. Chang et al. (2012) also discussed that students have to constantly review, elaborate, organize, plan, and adjust their problem-posing procedure and revisit the mathematical concepts to correctly pose mathematical problems. Students organize their thoughts during this process and make more connections to the mathematical concepts which leads to deeper conceptual understanding. Regarding students' knowledge of problem structure, problem-posing activities such as "What-if-not" (Brown & Walter, 1990) and reformulating given problems guide students to explore the structure of the problems instead of just focus on finding the answers (Stoyanova, 2003). English (1997, 1998) compared student-generated problems before and after a problem-posing intervention and concluded that students were able to pose problems with more complex structures by the end of the interventions. Moreover, researchers in extant literatures suggested that problem-posing was able to create this natural link between formal mathematics curriculum

in school with the real-world situations students encountered outside classroom (Ellerton et al., 2015; Dickerson, 1998). As introduced earlier, students were able to draw upon their funds of knowledge to generate problems (Walkington & Hayata, 2017). Students could integrate their own contexts and cultures to the problems they wrote which helped them to see the real-world application of the mathematical concepts and procedures. Moreover, as real-world situations were rarely only connected to one mathematical concept, students were also able to make connections between the new concepts or topics they learned with their prior knowledge. These effects of problem-posing align with the constructivist theories and Silver (1994) and Dickerson (1998) also explained how problem-posing was beneficial with respect to helping students to develop and build their own intellectual scaffolds of knowledge.

Comparisons Between Problem-Posing and Problem-Solving

Following the discussion of why engagement in problem-posing can improve students' problem-solving skills, this section focuses on comparing the effects of problem-posing and problem-solving on students' mathematical learning and offers a theoretical explanation for the difference between these two learning activities.

Problem-posing and problem-solving are both student-centered instructional activities, but they differ in the features and formats of their tasks (Kojima, Miwa, & Matsui, 2015; Retnowati, Fathoni, & Chen, 2018). Problem-solving is a comprehension task since participants need to understand the problem context and derive a strategy based on the given information in the problem to reach a solution. On the other hand, problem-posing is a production task in which participants generate new mathematical problems or reformulate given mathematical problems.

As suggested earlier, problem-posing and problem-solving are usually implemented together in mathematical learning tasks. Nevertheless, some studies compared problem-posing

with problem-solving activities regarding their effects on students' procedural fluency, conceptual understanding, transfer to novel problems, and interests (Dickerson, 1998; Kapur, 2015; Mahendra et al., 2017). In Mahendra et al. (2017), students who participated in problem-posing tasks outperformed students who participated in problem-solving tasks in conceptual understanding, but students who participated in problem-solving outperformed them in adaptive reasoning. In Kapur (2015), the author examined the preparatory effects of problem-posing and problem-solving. In other words, students would participate in problem-posing or problem-solving activities before studying a new topic. The results indicated that the problem-posing activity was a more beneficial preparatory activity while problem-solving was critical in promoting students to develop deeper conceptual understanding. In Dickerson (1998), the author compared free, semi-structured, and structured problem-posing tasks with problem-solving tasks and concluded that problem-posing created more opportunities for students to understand, communicate, and make connections with mathematics and therefore was a more successful instructional strategy than problem-solving to improve students' problem-solving performance.

One theoretical explanation for the different effect sizes between problem-posing and problem-solving activities is related to cognitive load theory (Sweller, Ayres, & Kalyuga, 2011). Cognitive load theory provides a framework to connect students' learning outcomes with the levels of the challenges faced by students when participating in the learning tasks. Cognitive load refers to the total amount of working memory sources when students consciously participating in a learning task and can be categorized as intrinsic and extraneous cognitive load. Intrinsic cognitive load is imposed by the "intrinsic nature of the material" while extraneous cognitive load is imposed by the "manner in which the material is presented" (p.57). Besides the intrinsic and extraneous cognitive loads, there is also germane cognitive load in the framework. In

Sweller (1988), the author defined germane cognitive load as the cognitive load required to deal with the intrinsic cognitive load and thereby learn the content. However, since the initial development of the framework, the definition and the role of germane cognitive load has changed. According to Sweller, van Merriënboer, and Paas (2019), germane cognitive load does not impose a cognitive load but redistributes working memory from extraneous to intrinsic activities. This change in germane cognitive load explains why the total cognitive load is reduced when extraneous cognitive load is lower.

The theory suggests that learning tasks that minimize students' extraneous cognitive load are going to be more effective than those involving a higher level of extraneous cognitive load. Compared to problem-solving, problem-posing tasks usually require a lower cognitive load from students, since the main focus is on creating problems instead of solving problems. In Retnowati et al. (2018), the researchers asked the students to rate the cognitive load they devoted to the problem-posing and problem-solving tasks and the result revealed that problem-posing tasks required a lower level of total cognitive load. One explanation for the reduction of cognitive load is that problem-posing turns a goal-specific problem into a goal-free problem (Kapur, 2015). The goal-free effect is one of the instructional effects within the cognitive load theory framework and it refers to the situation that students who solved goal-free problems demonstrating better learning outcomes than those who solved goal-specific problems (Sweller et al., 2011).

Besides cognitive load theory, another theoretical perspective that has been discussed is how problem-posing could afford greater prior knowledge activation and greater contextual flexibility (Kapur, 2015). Researchers suggest that compared to problem-solving tasks, there is no constraint in the problem-space in problem-posing tasks. This means that students can bring in their prior knowledge and their interests, their communities, and their cultural backgrounds

into their own problems (Kapur, 2015; Walkington & Bernacki, 2015; Walkington & Hayata, 2017).

Methods for Literature Review

Eligibility Criteria

The eligibility criteria for studies included in this literature review cover the following areas: population, intervention, outcomes, study design, time frame, and publication sources. Studies that investigated problem-posing's effects on K-12 students were considered as eligible for inclusion. Since this literature review aimed to synthesize the effect of problem-posing, eligible studies had to include an intervention that contained problem-posing activities. As problem-posing teaching activities usually do not exist independently but are combined with problem-solving activities, interventions including both problem-posing and problem-solving were also considered eligible. Outcome variables included in this review were: students' problem-solving performance, problem-posing performance, general mathematical achievement, and attitudes towards mathematics.

Regarding the study design and publication sources, this review only included quasi-experimental studies and experimental studies published in English in peer-reviewed journals and books, thesis/dissertations, and conference proceedings published between 1992 and October 2019. This time frame was selected because *the Professional Standards for Teaching Mathematics* (National Council of Teachers of Mathematics. Commission on Professional Teaching Standards for School Mathematics, 1992) specified that mathematics teachers should promote classroom discourse for students to initiate problems and questions to their teachers and peers (p.45). When this mathematics teaching standard was published, there was an increase in

studies that implemented and investigated problem-posing activities' effects in mathematics classrooms.

Search Procedures

The initial database search was conducted in EBSCOhost using the following search terms: "problem posing" AND AB"math*". All databases on EBSCOhost appeared in this initial search, and the system returned peer-reviewed, English articles published between 1992 and 2019. To capture theses and dissertations, Open Access Theses and Dissertations, and OpenThesis were also included in the initial search. In total, 154 more articles were identified. In addition to the initial search, 12 more studies were captured through book chapters in Singer, Ellerton, and Cai (2015) and the reference list of Keşan, Kaya, and Güvercın (2010). After deleting duplicates automatically and manually, 478 articles were included for abstract screening. The reason that almost half of the articles were automatically deleted due to duplicates might be that the researcher selected "all databases" when conducting the initial search in EBSCOhost, and lots of the articles were included in multiple databases. The abstract and full article screening process details were included in the PRISMA flow diagram PRISMA flow diagram (see Appendix B1). After excluding studies based on the exclusion criterion, 21 quantitative articles were included (Arikan & Unal, 2014; Cankoy, 2014; K.-E. Chang, Wu, Weng, & Sung, 2012; Cotič & Zuljan, 2009; Demir, 2005; Dickerson, 1998; English, 1997, 1998; Fauziah, Hobri, Yuliati, & Indrawanti, 2019; Guvercin & Vebovskiy, 2014; Kapur, 2015, 2018; Lowrie, 2002; Mahendra, Slamet, & Budiyono, 2017; Ozdemir & Sahal, 2018; Priest, 2009; Suarsana et al., 2019; Walkington, 2017; Walkington & Bernacki, 2015; Xia, Lü, Wang, & Song, 2007; Yang & Lin, 2012). Additionally, 29 qualitative articles were captured during this search procedure to provide more perspectives to explain the findings in this literature review

(Adigüzel, 2017; Armstrong, 2013; Bonotto, 2013; N. Chang, 2007; Cifarelli & Sevim, 2015; English & Watson, 2015; Gade & Blomqvist, 2015; Irvine, 2017; Kitchings, 2014; Igor' Kontorovich & Koichu, 2016; Igor Kontorovich, Koichu, Leikin, & Berman, 2012; Kopparla & Capraro, 2018; Kotsopoulos & Cordy, 2009; Lavigne & Lajoie, 2007; Leung, 2013; McGraw et al., 2008; Munroe, 2016; Nivera, 2017; Panbanlame, Sangaroon, & Inprasitha, 2014; Pelczer & Gamboa Rodríguez, 2011; Pourdavood, 2003; F. Singer & Voica, 2013; F. M. Singer & Voica, 2015; Siswono, 2010, 2011; Stockton, 2010; Voica & Singer, 2013; Walkington & Hayata, 2017; Weber, Radu, Mueller, Powell, & Maher, 2010).

Results

This section analyzes and summarizes the characteristics of the problem-posing tasks, the scaffolding strategies instructors provided to support students' problem-posing, and the effects of problem-posing on students' mathematical outcomes. The summary of tasks and problem-posing effect sizes from the include quantitative studies are presented in Appendix B2.

Problem-Posing Tasks Structure

In this section, the researcher analyzes and categorizes the problem-posing tasks' structures to depict a general picture of the recent problem-posing studies and reveal the variance of the problem-posing tasks among these studies. As defined earlier in the introduction, problem-posing activities could differ drastically due to the broad definition. Hence, a summary of the problem-posing task structure could help future researchers and educators to understand and interpret problem-posing's effects more critically. The problem-posing tasks' structures can be examined from these perspectives: the structure of the tasks, the mathematical content embedded in the tasks, and the duration of the problem-posing interventions.

According to my analysis of previous problem-posing intervention studies, semi-structured tasks appeared to be the most widely used type. One possible explanation was that semi-structured tasks could provide students with guidance and scaffolding to some extent while still leaving space for students to personalize their problem-posing experiences, such as integrating their interests and prior knowledge into the problems. Additionally, the majority of problem-posing interventions usually included more than one type of problem-posing task. For instance, in Ozdemir and Sahal (2018), English (1997, 1998), Mayan (2019), and Fidan (2008), the interventions included both semi-structured and structured problem-posing tasks. In Demir (2005), Katranci (2014), Kurt (2015), Kopparla et al. (2019), and Salman (2012), the interventions included free, semi-structured, and structured problem-posing tasks. Some studies only implemented one type of task: in Kapur (2015, 2018) and Walkington (2017), the problem-posing interventions only included semi-structured problem-posing; in Yang and Lin (2012), the intervention only had structured problem-posing. One plausible explanation is that interventions with longer durations tend to employ multiple types of problem-posing tasks, while shorter interventions usually only implement one type of task. The average duration of the interventions with all three types of tasks is 36 days, and the average duration of interventions with one type of task is 7.2 days. The average duration for interventions with all three types of problem-posing is significantly longer than the rest of the interventions since Cotic and Zuljan (2009) implemented a one-year long intervention, and Xia et al. (2008) implemented a two-year long intervention which dramatically impacted the average duration of the included interventions.

Another perspective by which to analyze the problem-posing tasks is whether students are required to solve the problems they generated. While most of the problem-posing tasks required students to solve the problems, only one study was designated to explore if solving the

problems was beneficial for students' mathematical learning. In Kapur (2018), students were divided into two groups: generating both problems and the corresponding solutions and only generating problems. The author, therefore, compared the different effects of the two types of problem-posing tasks. The study results revealed that there was no significant difference between the two problem-posing tasks on procedural fluency and transfer. Students who generated both problems and solutions outperformed the other group on conceptual knowledge ($p<.01$).

Scaffoldings Provided for Students During Problem-Posing Interventions

As introduced earlier, the problem-posing intervention was described as an inclusive instructional activity that all students should benefit from. There was no apparent floor effect in any of the problem-posing studies included in this literature review. Nevertheless, without any scaffolding, students still were more likely to generate ill-formed, nonmathematical problems or problems similar to textbook problems that were low in cognitive demand (Chen et al., 2013; Silver & Cai, 2005). Hence, a set of feasible strategies is necessary to support students' meaningful participation in problem-posing. The scaffolding strategies included in this review referred to any teaching method or instructional material that the researchers or teachers utilized to support students to achieve the goal of generating their own mathematical problems.

There were three widely used scaffolding strategies in problem-posing interventions: instructors giving feedback to students during their problem-posing processes; peer interactions such as working in pairs or groups and exchanging generated problems for their peers to solve; and worksheets or handouts with problem-posing prompts. Other strategies that had been established by extant literature are: teaching students problem-posing techniques such as the "What-if-not" strategy in which the students listed the attributes of a given problem and chose one attribute to deny or alternate to generate a new problem (Brown & Walter, 1990; Dickerson,

1998); the "authentic audience" effect in which student-generated problems were assigned to others to solve to therefore motivate students' active participation in problem-posing (Crespo, 2003); integrating familiar contexts, settings, and artifacts into the problem-posing activities to promote successful problem-posing (Bonotto, 2012; English, 1997; Walkington & Bernacki, 2015); having students work in pairs or groups to provide peer scaffoldings for each other (Gade & Blomqvist, 2015); instructors modelling problem-posing for students (Demir, 2005; Priest, 2009; Xia et al., 2008); utilizing online learning modules (Chang et al., 2012; Suarsana et al., 2019); teaching students problem structure knowledge (English, 1997, 1998; Xia, Lü, & Wang, 2008); having students document their generated problems in journals (English, 1997, 1998); having students act out real-life scenarios to pose problems (Dickerson, 1998); and using student-generated problems to plan for a class stall at the school fair (English, 1998).

Combining Problem-Posing and Problem-Solving

There were 4 quantitative studies included in this literature review that compared the effects of problem-posing and problem-solving activities. In Mahendra et al. (2017), the authors implemented the Problem-posing learning model with the Realistic Mathematics Education Approach with treatment group one and the Problem Solving with Realistic Mathematics Education Approach with treatment group two. The authors did not specify a control group that followed conventional mathematical teaching in this study, and the research design is quasi-experimental. The Realistic Mathematics Education Approach shared by both groups focused on connecting the instruction materials with the realistic scenarios in the world to motivate students' engagement and make the geometry content more accessible. Participants in this study were selected from seventh-grade students at the Junior High School Jaten in Indonesia during the 2016/2017 school year using the stratified cluster random sampling technique. In total, 63

students were selected and the intervention lasted for a month. The mathematical content covered in this intervention included the properties, circumference, extent, and application of triangles and quadrilaterals. Pre- and post-tests were utilized to assess students' conceptual understanding and adaptive reasoning on the geometry material. The findings indicated that both groups of students achieved higher scores in the post-tests. The problem-posing group outperformed the problem-solving group in conceptual understanding but was underperformed in adaptive reasoning. The authors proposed that students in the problem-posing group achieved higher conceptual understanding scores because they had to put extra thought into understanding the material as they needed to generate new problems and solve the problems. On the other hand, the authors explained that students in the problem-solving group outperformed in adaptive reasoning because they participated in problem-solving. Students had to understand the problem, plan out a strategy, and then solve the problem according to the strategy. This process required students to think logically and systematically, which helped to improve their adaptive reasoning skills.

There were two studies included from Kapur (2015): Study 1 compared the preparatory effects of students generating both mathematical problems and solutions (problem posing and solving) and students only generating solutions (only problem-solving); Study 2 compared the effects of students only generating problems (only problem-posing) and only generating solutions (only problem-solving). Both studies implemented experimental research design with random sampling technique. The mathematical scenario used for problem posing and solving was about the mathematical concept of standard deviation. Seventy-two ninth-graders participated in Study 1, and the author concluded that there was no significant difference between the two groups on procedural fluency, conceptual understanding, engagement, or mental effort. The group that participated in both problem posing and solving outperformed the group

that only solved problems on transfer ($p<.01$), which assessed students' ability to adapt the knowledge they learned during the standard deviation instruction to a novel content: normalization. Seventy-one students participated in Study 2, and no significant difference in engagement, mental effort, or procedural fluency was identified. The problem-posing group outperformed the problem-solving group on transfer ($p<.05$) but was underperformed on conceptual understanding ($p<.01$). In a word, both groups that contained problem-posing achieved higher scores in "transfer." However, students who only participated in problem-posing activities scored lower in conceptual understanding when taking away the problem-solving component. The author concluded that problem-posing activity was a more beneficial preparatory activity while problem-solving was critical in developing deeper conceptual understanding.

Dickerson (1998) also compared the effects of problem-posing and problem-solving by implementing "Structured", "What-if-not", "Acting-out", and "Open-ended" problem-posing in three treatment groups and problem-solving instruction in two comparison groups. This study lasted for two years and was comprised of two separate sessions that each lasted a year. All participants were seventh-graders, while 180 students participated in the first year and 92 students participated in the second year of the study. As indicated by the treatment group activities' names, the author implemented various types of problem-posing activities ranging from the straightforward "Structured" tasks to the more innovative "Open-ended" tasks. Among the different tasks, "Structured" problem-posing appeared to be the easiest and quickest to improve students' problem-solving achievement, while the "What-if-not" was the most intriguing task and promoted rich and meaningful mathematical discourse. Overall, the findings concluded that all the groups that received problem-posing instructions scored higher in the Iowa Test of

Basic Skills (ITBS) problem-solving subtest than the comparison groups who only received the traditional problem-solving instruction ($p<.05$). From the results, the author implicated that problem-posing activities could create more opportunities for students to understand, communicate, and make connections with mathematics and therefore was a more successful instructional strategy to improve students' problem-solving performance.

Problem-Posing's Effects on Students' Mathematical Learning

The dependent variables among the included studies were categorized into four categories: problem-solving skills, mathematical dispositions, problem-posing skills, and general mathematics achievement. The criteria to differentiate problem-solving and mathematical achievement in this literature review were developed based on the definition of a mathematics problem-solving in Charles and Lester (1982). A problem-solving task is a task for which: (a) the person confronting it wants or needs to find a solution; (b) the person has no readily available procedure for finding the solution, (c) the person must make an attempt to find a solution. Therefore, to be categorized as a problem-solving task, the students should not have already learned clear strategies to solve the problems but should derive relatively novel understandings and strategies regarding the problem based on their prior knowledge. In this literature review, the measurement was coded as a problem-solving instrument if "problem-solving" was specified in the test name or the authors described the test as a problem-solving test; for measurements that did not have a clear description, conceptual understanding and procedural fluency tests were coded as mathematical achievement, while transfer and adaptive reasoning tests in which students were required to use their prior knowledge to understand and solve problems related to novel concepts were coded as problem-solving; standardized tests were coded as mathematical achievement if no clear description was provided. In addition to quantitative studies that

investigated these above learning outcomes, the researcher also discussed qualitative studies'
findings to better depict students' experience with problem-posing interventions and their
problem-posing performance.

Problem-Posing's Effects on Students' Problem-Solving Skills

Due to the growing attention problem-solving received in the recent decades and its close
relation with problem-posing, students' problem-solving skills were widely included as one of
the problem-posing interventions' effects in prior studies (Chang et al., 2012; Cotič & Zuljan,
2009; Dickerson, 1998; Kapur, 2015, 2018; Mahendra et al., 2017; Priest, 2009; Suarsana et al.,
2019). Cotic and Zuljan (2009) implemented a problem-based intervention with 179 third
graders and students formulated and solved problems derived from their real experiences. The
findings suggested that students demonstrated statistically significant progress in problem-
solving. Salman (2012) developed a ten-week program including problem-posing and problem-
solving activities with 95 sixth-grade students and found significant increase in students'
problem-solving skills. Suarsana et al. (2019) recruited 119 eleventh-grade students and
implemented a problem-posing intervention with both online and paper-based groups. Students
generated, modified, and solved their problems in the intervention and findings revealed
problem-posing progress in both groups.

All studies mentioned above have concluded that the problem-posing interventions
demonstrated positive effects on students' problem-solving skills to some extent, except for
Mahendra et al. (2017). In Mahendra et al. (2017), students were assigned to problem-posing
instruction condition or problem-solving instruction condition, and the problem-posing group
was outperformed by their counterparts in the comparison group in adaptive reasoning ($p<.05$).
Even though the problem-posing group performed significantly higher in conceptual

understanding ($p<.05$), the conceptual understanding measurement was coded as mathematical achievement in this literature review and will be discussed later.

Problem-Posing's Effects on Students' Mathematical Dispositions

Compared to conventional teaching strategies in which students are mostly passively receiving instructions from classroom teachers, problem-posing permits students an active role in the learning process (Ellerton, 2013). Extant literature had discussed how students' engagement with problem-posing could stimulate students' dispositions towards mathematics learning (Silver, 1994; Singer, Ellerton, & Cai, 2013). Among the studies in this literature review, Chang et al. (2012), Demir (2005), Guvercin and Vebovskiy (2014), Walkington and Bernacki (2015), and Xia et al. (2007) demonstrated findings aligned with the extant literature and concluded that the problem-posing interventions they implemented had successfully increased students' interest in mathematics. However, in Cotič and Zuljan (2009), Kapur (2015, 2018), and Ozdemir and Sahal (2018), no significant difference was detected in students' attitudes between the treatment and control groups. The three problem-posing activities from Kapur (2015, 2018) all only lasted for 2 hours: one hour lecture and one hour problem-posing. Hence, the insignificant difference in dispositions might be due to the short intervention. In Cotic and Zuljan (2009) and Ozdemir and Sahal (2018), the interventions' durations were one school year and three weeks, respectively. They both detected students' dispositions improvement in treatment groups but students' dispositions were not different from their counter parts in the control groups. One possible explanation for this phenomenon is the social interaction threats. As students and teachers in the control group could learn about the intervention implemented in the treatment group directly or indirectly from the treatment group students or teachers, they might imitate the intervention or develop a competitive attitude which could be a threat to the findings' internal validity.

In addition to studies that investigated problem-posing's effects on students' mathematical dispositions, researchers also analyzed the relation between students' problem-posing performance and dispositions (Cai & Leikin, 2020; Guo, Leung, & Hu, 2020; Headrick et al., 2020; Liu, Liu, Cai, & Zhang, 2020; Schindler & Bakker, 2020; Voica, Singer, & Stan, 2020). In Guo et al. (2020), the researchers analyzed 302 Chinese Miao students' problem-posing performance and their self-concept (students' expectations), intrinsic value (students' perceptions of the interest, usefulness, and importance of the task), and test anxiety related to mathematics learning. Students' problem-posing performance was evaluated from these three perspectives: the generated problems' complexity, quantity, and accuracy. The results suggested that higher self-concept, higher intrinsic value, and lower test anxiety were associated with better problem-posing performance. Headrick et al. (2020) studied students' spontaneous problem-posing, which refers to students posing problems without formal prompting. The researchers concluded that students exhibited more positive emotions in periods that contained spontaneous problem-posing than those without spontaneous problem-posing. Liu et al. (2020) studied the relation between Chinese eighth-grade students' domain-specific self-efficacy (related to specific mathematical content areas) and task-specific self-efficacy (related to specific learning tasks) and their problem-posing performance. The authors concluded that the correlation coefficient between task-specific self-efficacy and problem-posing is more significant than that between domain-specific self-efficacy and problem-posing. Additionally, the correlation started to decrease as the difficulty level of the tasks increased. The authors explained that when students knew the problems were labeled as "easy" or "difficult", they might be reporting their self-efficacy based on the difficulty level of the problem which made this phenomenon a prompt effect that needed more investigation in the future. Overall, the authors suggested that students

usually reported higher self-efficacy scores when the activity asked them to pose easier problems.

Problem-Posing's Effects on Students' Problem-Posing Skills

Studies investigating students' problem-posing skills after problem-posing interventions mainly focused on assessing the solvability, reasonability, novelty, complexity, and the mathematical structure of student-generated problems. For instance, in Cankoy (2014), the treatment group students posed significantly more solvable, reasonable, and complex problems ($p<.05$); in Chang et al. (2012), the intervention increased students' scores in accuracy, flexibility, elaboration, and originality significantly ($p<.001$). In Fauziah et al. (2019), the author used students' problem-posing performance to analyze students' creativity level and concluded that the treatment group students' problem-posing work was significantly more fluent, flexible, and novel after participating in the intervention ($p<.001$). Besides these problem-posing assessment criteria, English (1997, 1998) and Lowrie (2002) also analyzed the structures of the problems students posed. English (1997, 1998) suggested that students posed more multistep problems after the problem-posing intervention. English (1998) concluded that greater diversity in problem types was revealed when students were given informal contexts to generate problems ($p<.001$). However, students still generated most similar types of problems throughout the study, and no significant difference was found in the problem diversity between the treatment and control groups. In a word, problem-posing interventions effectively improved students skills to generate more complex problems and students performed better problem-posing with informal contexts than formal contexts.

Problem-Posing's Effects on Students' Mathematical Achievements

Students' mathematical achievement was measured in the included studies through standardized tests or researcher-developed mathematics tests. The researcher-developed measurements could be categorized into holistic scale measurements that generated a composite score and analytic scale measurements that generated sub-scores in procedural fluency, conceptual understanding, etc. In Cotič and Zuljan (2009), Demir (2005), Guvercin and Vebovskiy (2014), Ozdemir and Sahal (2018), Walkington (2017), and Xia et al. (2007), the authors utilized holistic scale measurements to investigate students' mathematical achievement and all have identified statistically significant positive effects. On the other hand, in Kapur (2015, 2018) and Mahendra et al. (2017), sub-scores of mathematical achievement were investigated. The studies in Kapur (2015, 2018) investigated the preparatory effect of problem-posing: students participated in a two-hour session to pose standard deviation problems in a given situation and then received one-hour instruction on standard deviation from the classroom teachers. Moreover, Kapur (2015, 2018) and Mahendra et al. (2017) compared problem-posing's effects on problem-solving instead of conventional instruction. The findings in these studies demonstrated that problem-posing interventions were at least as beneficial as problem-solving interventions in terms of improving students' mathematical achievement, which further emphasized the importance of incorporating problem-posing into students' mathematics learning.

Qualitative Studies on Problem-Posing

Even though the above quantitative studies demonstrated problem-posing's positive effects on students' learning outcomes, the qualitative studies helped to describe students' performance in problem-posing interventions and how students respond to different types of problem-posing activities.

Regarding students' problem-posing performance in different types of problem-posing activities, Gade and Blomqvist (2015) and English (1997, 1998) found that students posed more complex and diverse problems in informal contexts compared to formal contexts. In the formal context activities, students were shown a card with a number sentence on it. In the informal contexts, students were shown a photograph and were asked to generate a word problem based on it. The formal and informal contexts activities would be coded as semi-structured problem-posing and free problem-posing respectively in this meta-analysis. Similarly, Kopparla and Capraro (2018) examined one second-grade student's working progress while participating in problem-posing activities and noticed that the student was able to pose complex multi-step problems about mathematical topic she was never exposed to when she was given interesting real-life scenarios (e.g., visual of the pet shop). In Cifarelli and Sevim (2015), the authors concluded that the within-solution problem posing involved engaging individuals in meta-cognitive activities and played an important role of helping individuals to make conceptual progress. The within-solution problem-posing would also be categorized as containing free problem-posing according to the coding manual.

In qualitative or mixed-method studies on problem-posing, the impact of proper scaffolding strategies is also discussed. In Gade and Blomqvist (2015), the authors analyzed students' problem-posing process when they generated number-related and societal experience-related questions, and students would work together to pose problems to each other and reflect upon the problems posed by their peers. The authors suggested that students would challenge and counter-challenge each other in this process, which was evidence of students' self-regulation, volition, and independence. In Kitchings (2014), the author investigated students' problem posing that happened when teachers engaged students in discourse and concluded that all

problem-posing instances in the study occurred when students interacted with each other. Moreover, Bonotto (2013) evaluated fifth-grade students' problem-posing performance with real-life artifacts. The author found that students started to think critically and reflected upon the quality of the problems they posed once they started to solve the problems generated by their peers, which provided another evidence for the importance of peer interaction.

Besides investigating students' performance in different problem-posing activities, researchers also analyzed how students of different grade levels react to the same problem-posing task. In Cifarelli and Sevim (2015), the authors used a qualitative case study design to analyze two fourth-grade and one mathematics education graduate students' within-solution problem-posing processes. Students were presented with mathematical problems and they would generate multiple problems while trying to solve the problem in order to help them better understand the problems and come up with strategies. The authors concluded that the fourth graders did not necessarily transform their strategies into a general algorithm. They changed the numbers of the original problems to see if the multiplication strategy they used worked for other numbers. However, the graduate student focused more on using within-solution problem posing to find the general rule for array problems: the graduate student extended the 10×10 array problem to any $N \times N$ array problems. The graduate student and the fourth graders' problem-posing processes both extended their understandings of the original problems and therefore helped the students to make conceptual progress. With the somewhat disparate two cases, the study pointed out how students of different grade levels might handle problem-posing tasks differently even though they were all making progress conceptually during the problem-posing tasks.

In summary, these qualitative studies and mixed-methods studies demonstrated the importance of including qualitative analyses when exploring students' performance in problem-posing interventions. Otherwise, researchers could only conclude that students make progress in their mathematical learning but not explore how students generate the questions or how students respond differently toward the same problem-posing prompt.

Meta-Analysis on Problem-Posing's Effects

To further examine the effect of problem-posing on students' mathematical academic outcomes, the researcher conducted a meta-analysis with the 21 quantitative studies in this literature review. A random-effects model was employed with robust variance estimation (RVE) to correct for the intercorrelation between effect sizes when necessary (Tanner-Smith & Tipton, 2014). The summary effect of the meta-analysis ($g = 0.64$) indicated that problem-posing interventions tend to have a positive effect on students' general mathematical academic outcomes, which was supportive of extant studies. Specifically, the average weighted effect sizes of problem-posing interventions on students' problem-solving skills, mathematical attitudes, problem-posing skills, and mathematical achievement were 0.75 *SD*, 0.54 *SD*, 0.92 *SD* and 0.62 *SD*, respectively.

In addition to analyzing the main effect of problem-posing, this meta-analysis sought to explore if the structure of the problem-posing tasks, the duration of the intervention, students' grade levels, and the provided scaffoldings would impact the effectiveness of problem-posing. There is no prior review study on problem-posing that disaggregates the effect using these variables. The results suggested that combining free problem-posing tasks with semi-structured and structured problem-posing tasks will positively impact the effectiveness of problem-posing interventions. Additionally, by participating in longer duration problem-posing interventions,

students developed more positive mathematical dispositions compared to shorter interventions.
There was not enough evidence to conclude that students' grade level or peer interaction impacts
problem-posing's effects.

Chapter 3: Pilot Study

This chapter will present a preliminary pilot study conducted in Spring 2019. The pilot
study took place in a large urban community that was served by a non-profit dedicated to STEM
learning called talkSTEM, https://talkstem.org. The purpose of walkSTEM is to support students,
classes, or groups to take physical or virtual walks, and find mathematical concepts in the
architecture, art, designed objects, and natural elements around them. Although the initiative has
"STEM" in the title, the walks students create are often centered around mathematical principles
and use mathematics as a mechanism to engage with STEM. The scope of walkSTEM is quite
broad, and activities include curating a collection of video-based walks, providing teacher
professional development on math walks, supporting informal learning sites like zoos or aquaria
to create math walks, and catalyzing the creation of afterschool activities relating to math walks
for K-12 students. walkSTEM provides a framework (talkSTEM, 2019) for creating math walks
as a general guideline for educators and learners to refer to (see Figure 1).

Figure 1

The Design Framework for Designing a Math Walk Stop and a Math Walk Tour
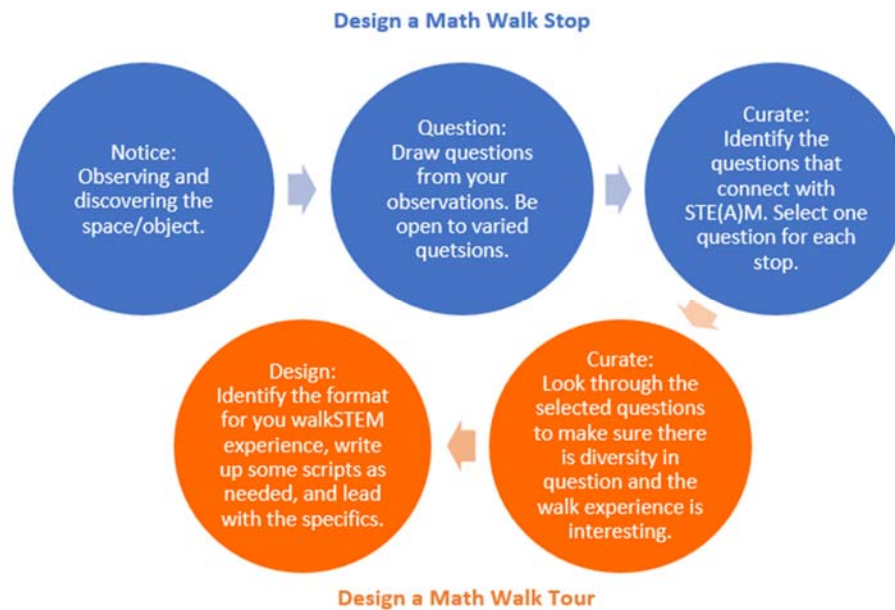
When creating math walks, participants first ***Notice*** – they observe and discover the space or object that they want to focus on. Next participants ***Question*** – they use their observations to generate questions they wonder about based on their noticing. Afterward, participants ***Curate*** – they review the questions they generated and identify one or multiple problems or scenarios that are related to STE(A)M topics at each location. After finishing selecting problems or questions at each stop, participants arrange and finalize the stops into a math walk tour. They look through the selected stops and corresponding problems to ensure that the walk covers different topics and the walk is intriguing for the audience. Lastly, the participants will determine which format – a physical walk or a virtual walk - they would like to implement after considering their own. The purpose of the pilot study is to investigate grades 3-5 students' problem-posing performance while participating in an after-school walkSTEM club. The research questions are:

What processes do club members use to create the walkSTEM stops?

What problem-posing products do club members create during the meetings?

What kinds of interactions do students have when they design walkSTEM questions and stops?

What scaffolding strategies are employed by the leading teachers to support students' problem-posing?

Methods

Participants

This pilot study employed a single case study design (Creswell, 2013). The walkSTEM club described in this chapter was located at Summer Hills STEAM Academy (SHSA; all names pseudonyms), which was a K-6 elementary school. Participants for this research study were recruited from within an existing walkSTEM afterschool club at SHSA. All ten students in the club consented to participate - four females and six males. There were 3 third-graders, 3 fourth-graders, and 4 fifth-graders. Two of the students were African-American, six were Latinx, and two were Caucasian. All of the students reported speaking English at home. At this school, 85.6% of students received free/reduced lunch. The club was led by two classroom teachers, Mrs. Fernandez and Mr. Garcia, at SHSA. Besides the classroom teachers, Mrs. Phillips, who led a walkSTEM afterschool club two years ago at SHSA, also participated in 5 meetings at the beginning of the semester to introduce the walkSTEM program to club members. All names are pseudonyms.

Data Collection and Analysis

Multiple data sources were collected in this study to strengthen the credibility of the research findings, including: student pre- and post-surveys (see Appendix C1), semi-structured interviews with students (see Appendix C2), semi-structured interviews with teachers leading the club (see Appendix C3), videos recorded for all 13 after-school club meetings, and students'

problem-posing work. More description of the activities club members participated in each after-school meeting are listed in Table 2. The researchers recorded videos as non-participant observers.

The teacher interview protocol questions focused on: teaching background, afterschool program planning, student behavior, and classroom instruction. The student interview protocol the pre- and post-survey asked students about their prior experience with problem-posing, their dispositions toward problem-posing and general mathematics classes, their experience of creating the walkSTEM stops, and their experience of leading the walk. The student pre- and post-surveys also included 42 items adapted from Linnenbrink-Garcia et al. (2010) that assessed students' situational interest and individual interest toward mathematics. In the surveys, students were asked to rate their responses to a certain statement about mathematics using a five-point Likert-type scale: strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. The survey included items that assessed triggered situational interest (affective experiences related to the environment – the walkSTEM club), maintained situational interest (a more involved and deeper type of situational interest that students associated with the content - mathematics), individual interest, and self-efficacy of students.

Table 2

The walkSTEM Afterschool Club in Action.

Session	walkSTEM Club Activities
Session #1	The researchers recruited students for this study. Students took pre-survey.

Session #2	Club members did their first "observing and asking questions" activity at the garden area on campus. They walked around the garden and wrote down questions they came up with in their journals.
Session #3	The teachers played previous math walk videos from the talkSTEM website to club members. Club members did the "observing and asking questions" activity at the hall way and the big tree in front of the school building.
Session #4	Club members did the "observing and asking questions" activity at the stairwell in the building and the math and science classrooms.
Session #5	The teachers invited Michael, a member of the prior walkSTEM club, to join this after-school club. Michael shared his walkSTEM experience at the echo room and the big number room.
Session #6	Club members did more "observing and asking questions" activities at the swings, the playground, the Geodome, the stairwell, the science classroom and the big number room. Club members voted for the stops they wanted to include in the final walk.
Session #7	Club members went back to some of the stops they voted for to do more exploration. The teachers and the club members finalized the math walk stops: the swing, the Geodome, and the big number room.
Session #8	The leading teachers decided to generate a virtual walk with video clips as the final product. Club members read the scripts and tried filming at the swing.
Session #9	Club members did problem-solving at the big number room to figure out the number of little squares on the tiles. Club members and the leading teachers

	generated the script for the introduction session of the virtual walk and practiced filming.
Session #10	Club members did more in-depth problem posing at the Geodome and selected the problems they wanted to use in the virtual walk.
Session #11	The teachers distributed the scripts for the swing and the big number room to students. Club members read through the scripts and practiced filming at the swing.
Session #12	Club members filmed at the big number room.
Session #13	Club members filmed at the Geodome.

To analyze the video clips, the researchers collaborated with participating teachers to identify themes that emerged from the problem-posing processes using thematic analysis (Braun & Clarke, 2006). Categories include: how students make connections with real-world scenarios when posing a problem; in which mathematics or science topics does the student pose problem about; what kinds of scaffolding strategies are implemented by teachers; how students interact with each other when posing problems as a group; how students alternate to think from a problem solver versus poser perspective when creating and leading the walkSTEM stops. More detailed description of this video analysis codebook is presented in Appendix C4. To analyze students' problems, a codebook with categories such as correctness, complexity, originality, and diversity was generated and utilized. These coding categories were adopted and adapted from other literature assessing students' problem-posing performance (Cai, 1998; Cai & Hwang, 2002; Chen et al., 2013; Zakaria & Ngah, 2011).

Results

Students' Problem-Posing Performance

According to students' pre-survey, some of them indicated that they had posed

mathematical problems before. However, the problems students generated at the beginning of the

walkSTEM program were mainly problems that forefronted domains other than mathematics.

For instance, the problems students created during the second meeting which took place in the

school playground were: "Why are there mushrooms?", "Why are there bunnies?" and, "Why are

there poles? (see Figure 2)" Although these kinds of observations can be a valuable starting

point, to engage students in meaningful mathematical problem posing and solving, appropriate

and efficient scaffolding strategies are critical.

Figure 2

Student's Problem-Posing Journal During the First walkSTEM Club Meeting

Even though the walkSTEM club members started with surface-level problem-posing

skills, the three final walk stops they created at their campus demonstrated the amount of

progress they made (see Table 3). The problems students generated were: "How do our bodies

help us move back and forth on a swing?", "How many little squares are there in the big number

room?", "How can you find out how many triangles there are on the Geodome?", and "What shapes can you see on the surface of the Geodome other than triangles?" Students learned to pose and solve meaningful mathematical problems with help from each other and their teachers. In our post-interviews, the teachers expressed how students' performance exceeded their expectations since most of the club members were third-graders and the initial problems they came up with were mainly not directly related to mathematics. Both teachers made comments that students were able to "think more critically, to see things differently, to see problems differently, and they can solve problems more on their own than they could before" and that "they are more self-guided," and the club meetings became "more student-centered and I'm guiding them less."

Table 3

The Virtual Mathematics Walk Scripts

Stop	
The Swings	
	Anna: For our first stop we are going to take you to one of my favorite parts of our school: the swings! Mia: The swings are so much fun because we can go up high and back and forth.

	Ellen: But do you know what makes this go so high and back? Look how they swing! See how they're moving their legs back and forth? Mia: When we move our legs back and forth we create force that makes the swings move! We move up away from the ground and then gravity pushes us back down. The more force we use with our legs the higher we move back and forth. So no matter if you're swinging by yourself or with a friend. No matter what, thanks to science you'll have a great time!
The Big Number Room	
	Anna: Up next on our tour: the big number. This area leads to so many places in our school. Ellen: It goes to the little kids' classroom, cafeteria, library, and bathroom. Mia: But why do you think we call it the big number? Michael: Not sure yet? Look closer, closer. See it yet? Look really closely. You can see lots of squares on the floor and inside the squares are smaller squares. How many little squares you think there are? Ellen: What strategies could you use to find the answer? Anna: I know a strategy we can estimate. We can use what we see to make a good guess.

	Michael: We can also multiply using the array model. We can count from the top row of big squares, then the squares on the side, and then we can combine two half squares to make one. There are seven number of squares that go on top and 29 that went on the side. If we multiply these two numbers, we can see that there are 232 big squares but when we add the half squares, we get the total of 236. Anna: Wow, it's a big number! Now you know why we call it the big number room.
The Geodome	
	Nancy: We've been to some really cool places in our school now let's go to one of my favorites: the big metal dome! Mathew: This is one of our favorite places to climb hang and use at the floor but look closely do you see anything interesting about the dome? Mia: Did you see all the triangles how many triangles do you think they are? Mathew: We can reuse our strategy of estimating again or we could just count! Mia: There are a total of 90 triangles around the dome. Did you notice any other shapes? You might notice other shapes like hexagons and trapezoids too! See? Ellen: Thank you so much for joining us on our walk stem tour. We had so much fun discovering mathematics and science around our school.

Students' Mathematical Dispositions

In this study, pre- and post-surveys were implemented and there were four students that had taken both surveys and the descriptive statistics is presented in Table 4.

Table 4

Students' Mathematical Disposition Descriptive Statistics

Student Name	Pre-Survey Disposition Mean	Post-Survey Disposition Mean
Mark	3.27	4.27
Anna	4.17	4.7
Nancy	4.03	4.6
Mia	3.8	4.4

According to the mean scores, all four students demonstrated more positive dispositions toward mathematics. The two leading teachers also mentioned that the students were more engaged in their school mathematics classes. Mr. Garcia mentioned that one of the students in the club, Mia, had "developed her mathematics cognitive abilities, her critical thinking" and had become one of the top students in his class. Mrs. Fernandez, who also had some club members in her classroom, discussed the mathematics tasks she implements in her class as an example to demonstrate students' progress in learning math. In the tasks, Mrs. Fernandez would first present a problem, and then she would let the students solve the problems in groups without much explicit instruction. She described that "in the beginning, I had to do a lot more guiding and it's gone to the point now that I do a lot less talking and I can kind of walk around and just kind of check to see that they're on the right track." The questions that students asked her while working on the mathematical problems went from "How do I do this?" to "Am I on the right track?"

Students' Interactions in the walkSTEM Club

Student-Led Problem-Posing

Michael, a former walkSTEM club member and current fifth-grader at the school, presented his experience with a previous walkSTEM club at the fifth meeting when he started to attend the weekly meetings of this club. Michael was invited to join the group because teachers noticed that the club members did not fully understand the purpose and meaning of creating the math walk, and Mrs. Phillips thought it would be helpful to invite Michael to come and describe his own experience.

While presenting the echo room and the big number room stops that his previous club had made to the club members, Michael gave some suggestions (Table 5): "use a lot of teamwork", and "start asking questions with your first thoughts." He indicated that "if you are by yourself then it will be a lot more difficult because you would not have other teammates talking to you and giving you more suggestions." He used the big number room as an example, describing how they had asked the question and estimated and counted the number of squares on the tiles and concluded that "you can't ask questions by yourself," and "you can't just answer those question by yourself not even if you're the genius." A second suggestion was brought up when Michael led the club members to the echo room. He started by sharing how they managed to generate their question of "why is there an echo in this room?" from their observation of "I can hear this echo." He encouraged the other club members to talk about their first thoughts of being in the echo room and tried to guide them to ask questions they wanted to solve from those thoughts. Eventually, the club members came up with problems such as: "How or what can stop an echo?", "Why is there no echo in the cafeteria?", and "how do all the objects in the room impact the sound?" from their first thoughts such as: "it's a loud voice" and "the ceiling is tall."

The club members seemed to be more interested in the stops that were introduced by Michael than those that were introduced by the teachers. During the sixth meeting, the teachers asked students to vote for potential places they would like to further explore. It was not surprising that the echo room and the big number room were among the most popular stops since students kept on talking about echoes and the tiles after hearing about them from Michael. On the other hand, the stop that the teacher introduced, the big tree in front of the school building, was never brought up. The teachers mentioned the impact Michael had in the post interviews. Mr. Garcia said: "I think the biggest, other contributing factors that helped us to move the program along was the use of older students to help the younger students. So we, we've had for example Michael - he had done the program before, he's a 5th grader and he was great about speaking at the students' level and getting them to think more critically about things and asking more questions. I think, better than sometimes me and Mrs. Fernandez can do… Probably after incorporating technology and video, he was a big factor in getting the program moving along and improving students' performance and behavior."

Table 5

Suggestions Michael Provided to New Club Members

Suggestions	Transcript
Use a lot of teamwork.	Mrs. Phillips: Can you tell them a little bit about um how you guys came up with the questions that you asked. Then how you wrote them down on paper and how we practiced that whole process a little bit. Michael: And you need to, like I said, I'll say it again, you need a lot of teamwork or else walkSTEM couldn't be a thing. You could be by yourself but you can't ask those questions by yourself, you can't just

	answer those questions by yourself. Not even if you're the genius of the whole entire world.
Start asking questions with your first thoughts.	Michael: Okay. So you start with a question. We walked in here and we started hearing this echo. Now we started talking about what can we do with this? How can we make a question out of it and how can we answer it. Now, what is your first thought of an echo? Right off your mind. Say what comes out when you think of an echo. Ellen: a loud voice. Michael: A loud voice. Michael: Sentences like this is what helps us. This is what makes a question.

Students Posed Creative Problems Beyond Their Knowledge

In this study, instances where students posed problems that they were not able to solve were relatively common. At the Geodesic Climbing Dome (Geodome) station (see picture in Table 3), students were curious about the shape, the structure, and the metal of the climbing dome. When students first arrived at this station, Michael asked them what were the first three things they noticed and wanted to ask questions about. Ellen asked why the shape of the climbing dome is bent while none of the bars were straight. Michael explained in his own words how he thought the structure of objects might be related to the shape and also indicated that he did not know the answer to this question. The teacher mentioned at the end that this was a good question to ask.

Table 6

Geodome Problem-Posing Transcript

1. T2: What kind of questions were we asking when we were doing the big room?
2. Anna: We were asking how many like little spurs in total there were.
3. T2: Can we do something like that here?
4. Ellen: Oh yeah! Yeah, how many triangles and little circles- like circles.
5. Anna: And nails.
6. T: You said the question was you're saying how many triangles total are there and how many circles are there total?
7. Ellen: Yeah, they could be some down here, but we just don't know. There could be some triangles down down down there 'cause [gets down and points to under the mulch on the ground] Oh, no, nevermind. Cut that out.
8. T: No, I don't think you necessarily need to cut it out. I think it's an interesting question. Like, does this keep going underground and we can't dig it up, right? So like how far done maybe, to like keep it sturdy. So I think that's an important observation too.
9. T: So one of the questions that you had is how many of the triangles there are?
10. Ellen: Yeah, and why do they have that little ugly material on it? And why is it colored grey?
11. T: Yeah, and you had an interesting hypothesis about that.
12. Ellen: Yeah, why is it colored grey and why do these go here?
13. Anna: And why is it so bumpy?
14. Ellen: Yeah, why is it bumpy?
15. T2: Hey girls, come over here real quick. You have a great perspective being really close to the shape. Stand over here where I'm standing. What else do you know?
16. Anna: Round
17. T2: So it's round shaped
18. Ellen: It's like an ice cream cone shape.
19. T2: What else do you see?
20. Ellen: The cars
21. T2: About the shape
22. Anna: It's um, you can see...
23. Ellen: There's other... There's hexagons!
24. T2: All what, what? Are there other shapes there in there?
25. Mia: You can add the triangles to make other...
26. Anna: There's hexagons
27. T2: Where's the hexagons?
28. Ellen: Right here. [points out shape]
29. T2: Is there another shape somewhere there? So we said rhombus, hexagon, and what else?
30. Mia: Square
31. T2: Square? Where's the square?
32. Mia: [points out where she thinks the shape is]
33. T2: Oh, but a square has to have what? Come back here, you guys. Too close again. So
34. Mia: Parallelogram
35. T2: So what did you notice when you stood over here that's different.
36. Anna: That there's a hexagon.
37. T2: There's a hexagon, what else?
38. Anna: You could make a house.
39. Ellen: Oh, there's um... I forgot what it's called. [points out trapezoid]
40. Anna: A triangle!
41. Ellen: No!

| 42. T2: There's a parallelogram. So is there more there? You guys are talking a lot about triangles. Is there anything else? |
| 43. Ellen: There's a really big pole I think I bent last year. Look. |
| 44. T2: I heard, I heard hexagon, I heard someone say rhombus, what else? |
| 45. Ellen, Anna, and Mia: Parallelogram. |

In another walkSTEM meeting when the club members revisited this Geodome, after reviewing their previous problem-posing progress, the teachers encouraged students to pose more problems about the dome (see Table 6 Transcript line 1-14). Students started to ask how many triangles, bars, circles, and nails were on the dome and why was the material of the bars bumpy. Students had previously visited the Big Number Room and had posed problems about how many little squares were there on the floor and why these square tiles were utilized. Therefore, it seemed that club members were able to transfer their problem-posing experience to new contexts.

Moreover, in this excerpt, the teacher guided students to view the geodesic dome from a different perspective (see Table 6 Transcript line 15-45). When club members stepped further away from the dome, they started to notice more geometric shapes such as hexagons, parallelograms, and rhombi. Even though the problems posed in this segment were not directly related to the initial problem which was beyond students' knowledge, they were still about the bars, the triangles, and the shapes of the dome. Teachers captured students' interests in the shape and structure of the geodesic dome and encouraged and guided them to pose more problems related to it. According to Silver (1994), this process of utilizing the problems generated by students to guide their learning demonstrated a feature of inquiry-oriented instruction, and students were encouraged to become self-directed learners throughout this process. Moreover, this feature helped to reduce the complexity of problem-posing since students' goal was not to pose a solvable problem but to ask about what they want to learn about. Unlike other higher-

level problem-posing work conducted by researchers to investigate secondary school students and pre-service teachers' problem-posing, the type of problem-posing used in this study was more achievable and suitable for younger students.

Scaffolding Strategies to Support Problem-Posing

To dig deeper into the transformations that students experienced, I examined transcripts of club meetings to identify successful strategies for supporting students in creating math walks. I identified three important strategies: (1) alleviate students' anxiety by using free problem-posing practices, (2) implement free and semi-structured problem-posing, and (3) utilize technology to inspire students' interest in creating math walks.

Alleviate Students' Anxiety with Free Problem-Posing Practices

The first strategy is to implement free problem-posing practices. In Stoyanova (1999), problem-posing tasks were categorized into free, semi-structured, and structured. Free problem-posing is defined as "a problem-posing situation when students are simply asked to pose a problem from a contrived or naturalistic situation" (Stoyanova 1999, 29). This type of problem-posing task can be both the easiest and the hardest. It is the easiest since there is no restriction on the problems students generate. This is also the hardest because there is not scaffolding embedded and students drive their own learning processes.

Free problem-posing was selected as the first learning task in the club because it gave students a risk-free environment to get acquainted with problem-posing. At the beginning of the club, students frequently asked the teachers if they were posing the "correct" problems or if the problems they generated were within their teachers' expectations. Some relevant transcripts are in Table 7. The first two conversations in Table 7 happened during the third club meeting when Mrs. Phillips showed students the math walk stops created by prior members at SHSA. Students

were asked to explore around the big tree in front of the school building and write questions down in their journals about the tree. Afterward, the teacher encouraged students to share out their questions with the rest of the group. The third conversation was during the wrap-up session of the fifth club meeting. Students were brought back to the cafeteria and the teachers encouraged students to practice free problem-posing without any specific instructions regarding what topic or content the problems should be about. From the students' responses, it was apparent that the students were seeking affirmations from their teachers since they were used to solving the problems their teachers provided.

Even though the problems students came up with at first during the free problem-posing activities were not as mathematically meaningful as the teachers might have expected, being able to generate problems freely helped to alleviate students' anxiety when participating in this new student-centered mathematical learning activity. Students became more and more confident throughout the program regarding posing and sharing mathematical problems.

Table 7

A Sample of Teachers Leading the Free Problem-Posing Activity

Meeting	Transcript	Scaffolding
3rd meeting	Nancy: I'm scared… Mrs. Phillips: You don't have to be scared. There's no wrong questions. Mrs. Fernandez: There's no right or wrong, you're just coming up with a question based on what you learned today.	Teachers addressed that there are no wrong questions
3rd meeting	Mrs. Phillips: Go ahead (Mrs. Phillips encouraged each student to share one question they posed about the big tree in front of the building). (Mark showed Mrs. Phillips her journal to ask if the questions she wrote were correct) Mrs. Phillips: Anyone. It doesn't matter. Remember our rule, you can ask any question. Mark: How old is the tree?	Teachers addressed that there are not wrong questions

	Mrs. Phillips: Thank you Mark.	
5th meeting	Mrs. Fernandez: Can we try to come up with at least one question in this cafeteria? Mrs. Phillips: So you asked one question maybe walk around the space a little bit and see if you can come up with some more okay? And you guys can walk around together and talk about it too.	Teachers encouraged free problem-posing

Implement free, semi-structured, and structured problem-posing tasks

Across the three stops that were included in the final virtual walk, the big number room task could be considered as a structured problem-posing as opposed to the swing stop and the Geodome which could be considered as free problem-posing. The big number room was one of the stops that Michael introduced to the club members during the third meeting and was voted to be the official stop in the club's walk later on. "How many little squares are there?" was the main problem students were wondering about, but students also came up with other problems in the big number room like why were there so many little square-shaped tiles and why the floor was slanted.

Using free problem-posing activity at the beginning of the club meetings helped students to be comfortable with asking questions and with not knowing the answers to the questions immediately. Next, students participated in a full cycle of creating, solving, and presenting the problems with semi-structured problem-posing tasks. Then, after students had created the big number room problem and discussed some potential strategies to solve for the number of small squares in this stop, they were able to transfer this experience to other stops like the swing and the Geodome and again use free problem-posing. The sequence of free problem-posing, to semi-structured problem-posing, back to free problem-posing, seemed especially effective.

Utilize technology to inspire students' interest in creating math walks

Another scaffolding strategy that effectively engaged students was the utilization of technology. It was apparent that as soon as the "virtual walk" idea was introduced, students' interest increased significantly. At the tenth meeting, Mr. Garcia and Mrs. Fernandez brought a camera to film for the first time, and students were so excited as they kept on talking about their favorite YouTubers, how the YouTubers interacted with viewers through the comments section, and what were some of the intros that they liked in videos. Mr. Garcia said, "Once we switched the focus from just … a tour to a video tour, something that got their attention and the performance… Their level of involvement and attention increased. They were more focused. Their generation is all about it [YouTube]... They wanted to do it so their attention was there."

Not only were students more involved in the process of generating the virtual walk, but the final video clips also looked quite professional. All students had played a role in making the videos, which could be another benefit of incorporating videos in the club. In a live math walk given to parents or peers, it would be highly possible that some students would be more vocal than their peers and would lead the math walk most of the time while the rest of the club members are not able to participate as much.

Discussion

This pilot study describes how problem-posing can be implemented in an afterschool club setting with elementary school students and how participating in this club impacted the club members' thinking about mathematics, posing mathematical problems, and seeing their surroundings through a mathematical lens. The walkSTEM afterschool club at SHSA was a successful experience in which both the teachers and the club members enjoyed discovering mathematics in their surroundings. They created their own virtual math walk around their

school's campus and acted as docents in short video clips. Our study suggests that creating math walks was beneficial for supporting students' mathematical attitudes. It also suggests that students tended to generate problems that were low in cognitive demand and were similar to textbook problems without any scaffolding. Therefore, it is important to support students' problem-posing with appropriate scaffolding strategies. Some strategies teachers implemented in this afterschool club including using free problem-posing as the introduction activity to help students to be familiarized with problem-posing and be less anxious about the correctness of the problems. Once students become comfortable with posing questions, teachers can implement a combination of free, semi-structured, and free problem-posing to enrich students' problem-posing experience. Additionally, this study discussed the importance of peer interactions in problem-posing. In this program, students were able to better understand the afterschool club and be more motivated in asking and solving questions after they heard a previous walkSTEM club member introducing the math walk from a student's perspective. Last but not the least, teachers can be more creative with the utilization of technology to inspire students' interest toward the problem-posing activity and to increase students' participation level in the program. The two teaches in this program connected the experience of creating and leading a math walk with creating YouTube videos which had a positive impact on students' participation level. In short, with these scaffolding strategies, elementary school students in this afterschool program were able to generate mathematically interesting and meaningful problems and they also developed more positive dispositions toward mathematics learning during the program.

Chapter 4: Methods

This study focused on students' mathematical problem-posing performance in a virtual walkSTEM club. Even though a positive relation between problem-posing and students'

mathematics learning has been documented (e.g., English, 1997; Kapur, 2015), a gap between

research findings in problem-posing and authentic implementation remains (Cai et al., 2015). To

contribute to the extant literature on problem-posing, this study employed a mixed-method

research design (Creswell, 2017) to investigate problem-posing activities' effects on high school

students' mathematical dispositions and problem-posing performance.

This chapter describes the research purpose and the research methodology. The

methodology section includes the description of the activities in the online walkSTEM program,

the data sources, the measurements, data analysis methods, and reliability and validity evidence

of the study.

Research Purpose

As summarized in the prior literature review, extant studies suggest that problem-posing

is positively related to students' problem-solving skills (Cai & Hwang, 2002), academic

achievement (Chen et al., 2013), and mathematical dispositions (Cai & Leikin, 2020; Chen et al.,

2013; Liu et al., 2020). However, there are still unanswered questions regarding the associations

between these variables. For instance, in Liu et al. (2020), the authors indicated that the

correlation between students' problem-posing performance and mathematical dispositions was

not linear and was smaller when students were engaged in more difficult tasks. Moreover,

compared to the prevalence of problem-posing in mathematics education, problem-posing is still

a fairly new instructional activity and most of the educators might not know enough about this

activity enough to implement problem-posing with their students. This study aimed to compare

the different types of problem-posing activities and investigate students' dispositions and

performance in these activities to provide some insights for educators when implementing

problem-posing. Additionally, the online problem-posing program in this study was different

from any prior studies as the instructors and the researcher implemented all of the activities

online without any in-person meetings, including: pre-intervention training webinars with

instructors, recruitment of participants, pre- and post-survey, weekly meetings, check-in

sessions, final presentations, and post-intervention interviews. With remote learning becoming

more prevalent and important these days, the exploration of this online program could examine

the advantages and challenges of integrating problem-posing into virtual schooling. In short, this

study focused on utilizing a mixed-research design to comprehensively analyze students'

learning process and dispositions in this online problem-posing program.

This study employed the mixed-methods research design to provide a more

comprehensive investigation for students' problem-posing performance and their interaction with

peers and instructors in this program (Creswell, 2002). Specifically, the research design is a

quantitative analyses first sequential equal weight mixed-methods design (QUAN→QUAL)

according to Bryman (2015). Bryman (2015) also summarized different ways to combine

qualitative and quantitative research and the methodology of this study would be categorized as

Triangulation, *Explanation*, *Unexpected results*, and *Illustration*. *Triangulation* refers to using

the combination of qualitative and quantitative research to triangulate findings. *Explanation*

refers to studies that use qualitative research to explain findings generated from quantitative

research, or vice versa. *Unexpected results* means that the qualitative and quantitative research

are combined to better understand unexpected results from either the qualitative or quantitative

analyses. *Illustration* means that the qualitative research is employed to illustrate the findings

generated from quantitative research. In this study, the quantitative analyses were first employed

when there were quantitative data associated with the research questions and the qualitative

analyses were employed to conduct comparison between quantitative and qualitative results,

triangulate the findings, provide context and examples to explain the findings, and illustrate students' performance with their problem-posing behavior and work in this program.

Choy (2014) summarized the strengths and weaknesses of quantitative and qualitative methodology approaches. The data analyses and findings in quantitative approach can be reliable and consistent but there is no human perception nor depth experience description, and it generally required robust and large-scale data to address complex research questions. On the other hand, qualitative research provides opportunities for more detailed exploration and can help researchers to analyze the behaviors, beliefs, and assumptions of the participants. However, qualitative research findings could be affected by the researchers' positionality and interpretation and the researcher needs to devote significant amount of time to do intensive data analyses. As discussed earlier, this study aimed to address the gap between research findings on problem-posing and authentic implementation of problem-posing activities in students' mathematical learning. Therefore, both methodologies were required in order to not only examine the effects of problem-posing but also explore the process students generating problems and instructors implementing problem-posing,

In the quantitative investigation, the study explored how students' problem-posing, problem-solving, conceptual understanding, and procedural fluency were associated with students' dispositions towards mathematics and the trajectories of students' problem-posing performance throughout the program. In the qualitative investigation, students' problem-posing work, students' and instructors' pre- and post-survey responses, students' and instructors' interviews were employed to further analyze the problem-posing activities' impacts on students' mathematical dispositions and problem-posing performance by the end of the walkSTEM program. The research questions addressed in this study are:

1. *How does designing and leading a math walk shape students' dispositions toward math and toward creating their own math problems?*

2. *How does designing and leading a math walk impact students' performance in posing mathematical problems?*

3. *What interactions do students have when they experience math walks and design their math walk questions and stops?*

4. *Do relations exist between or among students' problem-posing skills, problem-solving skills, conceptual understanding, procedural fluency, and mathematical dispositions?*

5. *How do instructors scaffold students' problem-posing procedures during the program?*

Research Methods

Population

The study participants in this study were recruited from an existing college preparation program in a private research university located in a large southwest metropolitan area. The program's objective is to help first-generation students from designated schools who desire to pursue college to transition from high school to college. The college preparation program offers services such as weekly high school course tutoring sessions, test preparation, financial aid and scholarship application, career guidance and planning, etc. The program accepted students from 10 schools and the students in these schools are 59.88% Hispanic, 33.19% African American, 3.90% White, 1.43% Asian, 0.45% American Indian, 0.1% Pacific Islander, and 0.85% Two or more races. Additionally, 76.45% of these students are economically disadvantaged, 24.38% are English Learners, and 8.99% are special education students.

The study participants were recruited through the following procedures. Text messages with the link to the parental consent form were sent to students' parents. Students were then given a pre-assessment that included an assent form during the first walkSTEM program meeting online. All students and parents enrolled in the college preparation program at the beginning of the semester were contacted in this manner. Students who consented to participate were compensated with $20 gift cards by the end of this walkSTEM program once they finished the post-assessment. In total, 35 out of 53 high school students in this college preparation program were recruited and there were 26 Hispanic, 7 African American, 1 Asian, and 1 two or more races. Among the 35 students, there were 24 female and 11 male students. All participants were highs school students and there were 1 freshman, 13 sophomores, 4 juniors, and 17 seniors in this program. Participant characteristics are listed in Table 8, including students' races, grade levels, self-reported Mathematics grades they usually received, pre- and post-survey interest rating, pre- and post-survey problem-posing complexity scores, the number of videos and #STEMlens problems students completed and the averaged problem complexity scores, and the Final Walk problem's complexity scores.

Table 8

ID	Race	Gender	Grade	Math Grade	Pre-Interest	Pre-Complex	Post-Interest	Post-Complex	# of Videos	Video Complex	# of #STEMlens	#STEMlens Complex	Final Walk Complex
S1	Black	Female	12	B	3.625	4	3.875	5	7	3.57			4.00
S2	Black	Female	10	A	4.5	4.5	4.5	4	4	3.25	3.5		
S6	Hispanic	Female	12	B	3.75	1							
S7	Hispanic	Female	10	A	3.875	3							
S8	Hispanic	Female	12	B	3.625	2			3	2.67	2	3.50	4.00
S9	Hispanic	Female	11	A	3.75	3.5	3.125	4	1	3	2	3.50	4.00
S11	Hispanic	Female	12	B	3.75	1	5	2	6	3.20	1	3.00	
S12	Hispanic	Male	10	B	3.625	3			7	3.29	1	3.00	
S13	Hispanic	Female	11	B	2.25	1.5							
S14	Hispanic	Male	10	B	3.875	5	4.25	3.5	7	3.43	1	3.00	
S15	Hispanic	Male	12	B	3.375	0							
S17	Black	Male	11	B	1.5	0.5							
S18	Hispanic	Male	10	B	2.75	3	3	3	14	3.07	18	3.89	4.00
S19	Hispanic	Female	9	A	3.625	3.5	4.375	5	20	3.26	5	3.40	4.00
S20	Hispanic	Female	10	B	3.5	3.5	4	4	3	3.00			
S24	Hispanic	Male	10	B	4.625	0							
S25	Hispanic	Female	12	A	3.75	3.5	3.5	3	5	3.20	1	3.00	3.50
S26	Other	Male	10	A	4	1.5							
S28	Hispanic	Male	10	B	4.5	4.5	4.25	3					
S29	Hispanic	Female	12	A	2.75	2.5							
S30	Black	Female	11	B	3.5	3.5							
S32	Hispanic	Female	12	A	4.125	3							
S33	Other	Female	12	A	3.875	4	3.75	4.5	34	3.24	2	3.00	4.00
S35	Hispanic	Female	12	B	3.5	2.5	4	2	17	3.24	2	3.50	4.00
S36	Hispanic	Female	10	C	3.5	1	3.125	0	2	3.00			3.00
S37	Hispanic	Female	12	A	3.875	2.5			1	3.00	2	3.00	4.00
S38	Hispanic	Female	12	A	5	2	5	2.5					3.50
S39	Hispanic	Female	12	B	3.375	0							

S40	Hispanic	Male	12	B	2.5	0					1	3.00	4.00
S42	Black	Female	10	B	3.875	3							
S43	Hispanic	Male	12	A	4.5	0							
S44	Black	Female	10	B	2.125	2	2.875	4	1	3.00			
S45	Hispanic	Male	10	B	4.625	3	4.125	1.5					
S49	Hispanic	Female	12	A	4.125	3			1	3.00			
S53	Black	Female	12	A	3.375	2.5	3.5	3	2	3.00	1	4.00	

Besides student participants in this study, suggestions and feedback from the instructors about the walkSTEM program were also collected. The 13 instructors in this program were tutors in the college preparation program, who were all undergraduate students from this private research university. Among the instructors, there were 7 instructors who were Hispanic, 3 who were White, 2 who were Asian, and 1 who was African American. Before the beginning of the program, the researcher met with the instructors and staff in this college preparation program for two webinars to introduce the walkSTEM program, the benefits of having students posing problems, and ways to scaffold students' problem-posing activities. During this first webinar, the researcher introduced the problem-posing concept to the instructors and staff and presented several examples of problem-posing, which included walkSTEM videos created by other educators and students and some #STEMlens photos. Instructors were then encouraged to do problem-posing themselves and submit at least one #STEMlens photo along with the question(s) to the online discussion board. The discussion board was later shared with students so that students could review their instructors' problems and make comments about the pictures or problems. During the second webinar, the researcher introduced the Final Walk project to instructors which require each groups of students to create a walk together and present. In order to better support instructors to guide students' problem-posing, instructors were also brough to a Mursion Simulation Environment (Appendix D4) which was hosted by staff from the university's teaching lab. Instructors were presented with the scoring rubric of #STEMlens activity and were presented with two simulation tasks. In the first task, instructors met three virtual students who had different issues with their #STEMlens photos. The instructors had to review these students' photos, give them feedback and guide them to moderate their photos or questions. For the second task, instructors were given a scenario of one student's #STEMlens

work and were asked to support this student in turning this #STEMlens photo into a full STEM walk. The problem of this virtual student's #STEMlens was similar to a textbook problem and instructors were expected to guide students to pose more creative and complex problems. With these two webinars and the Mursion Simulation, instructors should be able to understand the different problem-posing activities in this program, and how to guide students' problem-posing by reviewing their work and provide them with feedback.

walkSTEM Program

As introduced earlier, this online program was designed based on the Create Your Own walkSTEM initiative developed by the talkSTEM non-profit organization. talkSTEM's mission is the development of future generations of female and underrepresented STEM leaders. The organization provides a talkSTEM Learning Suite Resources that include various resources for K-12 educators in all settings to engage their students in STEM learning activities. The walkSTEM initiative was developed by Drs. Dhingra and Whitney. Dr. Whitney is the founder of the National Museum of Mathematics and the program advisor for walkSTEM. Dr. Dhingra is the founder and CEO of talkSTEM. The two of them created many walkSTEM tours in a variety of settings that highlighted real-world, inquiry-based connections between real world objects and spaces and STEM topics. Students, parents, and educators can take on these tours led by walkSTEM docents or fellows in which they learn about and discuss the STEM connections in real world settings. The Create Your Own walkSTEM provides students the opportunity to not only experience the tours but also contribute to the walkSTEM tours. Students can create "stops" based on objects in their surroundings (e.g., schools, communities, neighborhoods), generate a tour with their self-created "stops", and lead their audience on the tour while they introduce their questions and answers or strategies at each "stop".

I started to get involved with talkSTEM since 2017 and I've been working closely with

the founder and CEO of talkSTEM, Dr. Dhingra. As a researcher interested in problem, the

inquiry-based learning activities and the procedures in which students creating the math walks in

walkSTEM allowed me to explore students' problem-posing performance and address the gap

between research findings and authentic implementation. I first investigated the walkSTEM

program at this elementary school in the pilot study. The findings suggested that students were

able to take advantage of the problem-posing activities and also developed more positive

dispositions. Furthermore, this online walkSTEM program with high school students provided

me with the opportunity to explore higher grade-level students' problem-posing experience and

identify effective scaffolding strategies to support them. I partnered with Dr. Dhingra to

transform the in-person Create Your Own WalkSTEM initiative into an online walkSTEM

program. We worked together to plan and lead the two webinars with instructors, and create the

instructional materials including video-watching questionnaire, lesson plans, design worksheet,

and planning sheet (Appendix D) and rubrics (Appendix E) used in the online program. The

design worksheet (Appendix D3) was adapted from the Create Your Own walkSTEM Teacher

Guides (talkSTEM, 2019). The #STEMlens and Final Walk rubric (Appendix E) were adapted

from a talkSTEM blog post (talkSTEM, 2020). More description about the content and the roles

of these instructional materials are discussed below.

An outline of the development process of this program is presented in Figure 3. The

outline includes the recruitment of students, lesson planning, instructor trainings, and weekly

check-in meetings. The training webinars aimed to provide instructors a clear understanding of

the nature of these walkSTEM activities by presenting #STEMlens and walkSTEM walk

examples, having instructors create #STEMlens photos themselves and evaluate their self-

generated problems, and practicing scaffolding students' problem-posing using with the Mursion simulations. As indicated above, I was involved in the development of this program and I worked closely with Dr. Dhingra and Dr. Walkington throughout the planning the training process. I partnered with Dr. Dhingra to create the lesson plans and modify the activities and instructions on the lesson plans (Appendix D2) based on the feedback we received from instructors during the check-in meetings. Dr. Walkington set up the simulation contexts (Appendix D2) and led the Mursion simulations so that instructors could experience different simulated teaching scenarios and be prepared to support students in different settings. For instance, there were students who were not motivated enough to participate, students who created problems similar to text-book questions, students who didn't put clear markup on their #STEMlens photos, etc.

Figure 3

Outline of Planning and Development Procedures for the walkSTEM Program

Plan Learning Activities	• Collaborated with Dr. Dhingra to plan the video-watching, #STEMlens, and Final Walk activities and create rubrics.
Create walkSTEM Gameboard	• Created the walkSTEM Gameboard for students to document their problem-posing work.
Recruit Students	• Recruit students via online meetings with parents in the college preparation program.
Training Webinar #1	• Collaborated with Dr. Dhingra and Dr. Walking to plan and lead the webinar to introduce video-watching and #STEMlens activities to instructors.
Create Lesson Plans	• Collaborated with Dr. Dhingra to create lesson plans for each online meeting.
Check-In Sessions	• Led the check-in sessions with instructors to discuss students' learning progress and receive feedback.
Training Webinar #2	• Collaborated with Dr. Dhingra and Dr. Walking to plan and lead the webinar to introduce Final Walk. Dr. Walkington designed and led the Mursion simulations.
Create and Modify Lesson Plans	• Created and modified lesson plans for instructors based on the feedback from check-in sessions and my observation during the online meetings.
Check-In Sessions	• Led the check-in sessions with instructors to discuss students' learning progress and receive feedback.

In the virtual online walkSTEM program, there were three main activities for students: (1) watching walkSTEM videos; (2) taking #STEMlens photos and posing questions, and (3) creating a virtual walkSTEM walk as the final project, and presenting the walk in groups. The walkSTEM videos were short videos in which prior walkSTEM club members or staff talk about STEM-related problems in their surroundings. The STEM problems could be based on a place (e.g., a university, a shopping mall, a park), an activity (e.g., basketball, playing music), or a STEM topic or concept (e.g., geometry, biology, plants). After watching the walkSTEM videos, students were asked to complete a video-watching questionnaire (see Appendix D1). They documented the problem being discussed in the video, explained if they think the video is related to mathematics, created problems about the scene or the object in the video, and answered whether they liked the video or not.

The #STEMlens photo was a problem-posing activity in which students took photos of their surroundings, marked up the photos, and posed problems based on the photo and markups. Students' #STEMlens photos were assessed by their instructors using the rubric presented in Appendix E2. The #STEMlens rubric aimed to evaluate the quality of the used photo, the clearness of the markup, and the question's connection to the photo. A full-credit #STEMlens photo should be clear and eye-catching with clear markup and specific question referring to objects in the photo. The walkSTEM walk was the final project of the program. Each student designed three walkSTEM stops and each stop was comprised of a #STEMlens photo or short video, a STEM problem, and the corresponding answer or strategy to the problem. Students worked in groups to provide feedback and suggestions to each other. They each selected one stop from their STEM walk and presented in groups to their peers, parents, staff, and instructors. The walkSTEM project and the presentation were scored by their instructors using the rubrics in

Appendix E1. The Final Walk rubric included the same assessing categories as #STEMlens's

rubric. The main difference was with the walkSTEM Tour Planning and Design part, which

required students to complete the planning sheet and design worksheet (Appendix D3). The

planning sheet was designed to guide students to select a theme for their group's Final Walk and

choose a format for their presentation (e.g., pre-recorded video, slides presentation). The design

worksheet helped students to explore the various problems they could pose with a #STEMlens

photo, choose one problem to solve, and explain how this problem could be connected to their

group's theme.

Besides the problem-posing activities, I also developed a gameboard (see Figure 4) for

students to document the walkSTEM videos they watched and #STEMlens photos they created.

Based on the number of videos and photos students completed, their scores on the gameboard

would grow accordingly and their fictional creatures in the game would evolve into higher-level

creatures.

Figure 4

walkSTEM Gameboard to Document Watched Videos and #STEMlens Photos

Welcome to your walkSTEM Gameboard
Put your first name here, You are level

1

And your title is Fictional Creature Name

Fictional

Creature

First Name **Put your first name here**

Welcome to the walkSTEM game!

You will use this game board to keep track of your progress in the walkSTEM game and project.
There are only 3 tabs you will use in Oct - early Nov:
My #STEMlens, My walkSTEM videos (in-class), and my walkSTEM videos (bonus).
You can keep track of your level in this game using the **My Level** tab.
What pokemons can you win?

AFTER NOV 7TH, you will plan your walkSTEM Project (in November) using the **My walkSTEM Project** tab.
DO NOT view this tab until your tutor go through it with you.
1) **My #STEMlens** tab
   Here is where you win points for your photos taken in your places with your questions/observations.
     a) for each #STEMlens photo you take, make sure to follow the guidlines
     b) upload your photo to Canvas discussion board
     c) you will earn points based on the rubric

2) **My walkSTEM Videos (in class)** tab
   Here is where you win points for each walkSTEM video you watch + the video-watching form you complete.
     a) for each walkSTEM video you watch in class time, complete a video-watching form
     b) mark with an x in the first yellow column to show you've done this
     c) win points for each form that you submit

3) **My walkSTEM Videos (bonus)** tab
   Here is where you win EXTRA points for each walkSTEM video you watch + the video-watching form you complete.
     a) for each walkSTEM video you watch after class time, complete a video-watching form
     b) mark with an x in the first yellow column to show you've done this
     c) win points for each form that you submit

It's as simple as that - have fun!
You can use My Pokemons! tab to select your favorite pokemons!

Watch the video and complete the questionnaire Check Off (use an x)	Date	walkSTEM place/theme	Title	XP (total # of points you could win)	Link	Points Earned	Video-Watching Questionnaire Link	Notes to yourself
x		Starbucks	What's the difference between Starbucks' nitro brew and a carbonated soda?	0	watch the video	0		I never realized there was no brew. I'm surprised that the br... soda are totally different fro...
	10/17	SMU	How do trees function?	10	watch the video		click here	
	10/17	SMU	How symmetrical is it?	10	watch the video		click here	
	10/26 - 10/30	SMU	How Does a Sun Dial Work?	10	watch the video		click here	
	10/26 - 10/30	Love Field Airport	Campanile Window - Giving Shape to Movement	10	watch the video		click here	
	10/26 - 10/30	Dallas Art District	What is the Shape of the Traffic Bollard?	10	watch the video		click here	
	11/2 - 11/6	Starbucks	How Many Starbucks Drink Combinations Are There?	10	watch the video		click here	
	11/2 - 11/6	Starbucks	What Effect Does Temperature Have on Brewed Starbucks Coffee?	10	watch the video		click here	

Link to #STEMlens pictures	CHECK OFF (use an x)	#STEMlens Number	Date	Your math/science/STEM/STEAM observation/question	XP	Notes to yourself	Points Earned
https://smucommons.instr	X	1	9/17	How much of the roofs area is covered in shade? Does the amount of shade change throughout the day?	0	This photo is about my neighbor's house's roof. I posed 2 questions based on this picture.	0
		2			10		
		3			10		
		4			10		

Students met with their instructors 9 times for the walkSTEM program during the semester, including three longer sessions (one 90-minute session and two 120-minute sessions), five 30-minute short check-in sessions, and one final presentation session. The researchers, the program coordinators, and the college preparation program staff met with the instructors for training purposes before implementing the program. More descriptions of the instructional activities in each session are listed in Table 9 and the researcher provided detailed lesson plans (see Appendix D2) for all sessions to instructors before each session.

Table 9

Student Activities in Each walkSTEM Session

Session	walkSTEM Program Activities
Session #1	Students completed the pre-survey. Instructors introduced the walkSTEM program, the gameboard, and the #STEMlens photos. Students watched one walkSTEM video and completed the video-watching form.
Session #2	Students watched three walkSTEM videos and completed three video-watching forms. Instructors checked in with students regarding their #STEMlens photos.
Session #3	Instructors checked in with students regarding their #STEMlens photos. Students submitted at least one #STEMlens photo. Students who finished earlier would watch two more walkSTEM videos and completed the forms.
Session #4	Instructors introduced the walkSTEM project (the walkSTEM tours) to students by watching previous student-created walkSTEM tour videos. Each student completed a walkSTEM project planning sheet and started to work on the first two walkSTEM stop design worksheets.

Session #5	Students completed the first two walkSTEM stop design worksheets and finalized at least one walkSTEM stop including the question, the photo/video, and the response to the question for the stop. Students who finished early would watch one more walkSTEM video and completed the form.
Session #6	Students started to work on the third walkSTEM stop design worksheet and watched one walkSTEM video and completed the form.
Session #7	Students worked in groups to each select one walkSTEM stop from their projects to form a group walkSTEM tour. Students gave feedback to each other, wrote the script for their walkSTEM tour, and created the slides for the presentation on STEM day.
Session #8	Students finalized their group's walkSTEM tour presentation and rehearsed.
Session #9	Students presented their group's walkSTEM tour to their parents peers. Students completed the post-survey after the presentation.

Data Sources

As indicated earlier, six data sources were collected in this study: the student pre- and post-survey, the instructor pre- and post-survey, the instructor mid- and post-interview, the student post-interview, the student work, and the video recordings of all of the walkSTEM meetings.

The students' pre- and post-surveys are presented in Appendix F. Students took the pre-survey during their first walkSTEM meeting and the pre-survey included demographic information, problem-posing, problem-solving, conceptual understanding, procedural fluency,

and mathematical dispositions survey items. The measurement instruments that were used in this study are further described in the next section.

The student post-survey was implemented after the final presentation day and the post-survey only included items on students' problem-posing skills and mathematical dispositions. The problem-solving skills, procedural fluency, and conceptual understanding items were not included. It would be problematic to conduct research which suggested that students' change in these three aspects was entirely due to this walkSTEM program. There was no specific content covered in this program and students only met nine times during the semester.

Students who participated in all three walkSTEM activities (i.e., watching the walkSTEM videos, #STEMlens photos, and walkSTEM project and presentation) were selected to be interviewed using the interview protocol in Appendix G after their final presentations. The interview protocol focused on students' problem-posing experiences in the walkSTEM program, the difficulties or challenges in generating problems, and whether students' mathematics dispositions had changed after participating in this program.

To triangulate the investigation of students' performance in the program, instructors' perspectives were also collected. The instructors' role was to model problem-posing (the #STEMlens photos and video-watching questions) and support students' problem-posing in this program. The pre- and post-survey were implemented during the training session and after the completion of this program. The survey asked about instructors' attitudes toward problem-posing to analyze if leading the walkSTEM program impacts their dispositions. The instructors were interviewed two times in this program: after the fourth walkSTEM meeting and after the last meeting. The interview protocol is in Appendix G and the researcher used this semi-structured interview to ask about instructors' dispositions toward problem-posing, the walkSTEM program,

and how they thought of students' problem-posing performance during this program. The selection of the interviewed instructors was based on their ratings on the pre-survey. The pre-survey responses were grouped into three groups: high interest in problem-posing, medium interest in problem-posing, and low interest in problem posing. The researcher interviewed two instructors from each group. For the post-interview, if any of the previously-interviewed instructors were no longer leading the walkSTEM program, they would not be interviewed again. All instructors that led the final STEM walk groups were interviewed after the end of the program.

Measures

The student survey was comprised of three sections: (1) the mathematical dispositions items; (2) the problem-posing items developed by the researchers; (3) the procedural fluency, conceptual understanding, and problem-solving items adapted from the released Trends in International Mathematics and Science Study (TIMSS) 2011 grade 8 mathematics assessment items. The student survey is presented in Appendix F.

The dispositions survey items were adapted from the mathematical individual interest scale from Linnenbrink-Garcia et al. (2010) and were also implemented in the pilot study and other extant literature investigating students' mathematical dispositions (Walkington, 2013, 2017). The student interest survey included 8 items: (1) math is practical for me to know, (2) math helps me in my daily life outside of school, (3) it is important for me to be a person who reasons mathematically, (4) thinking mathematically is an important part of who I am, (5) I enjoy the subject of math, (6) I like math, (7) I enjoy doing math, and (8) math is exciting to me. Cronbach's alpha for the mathematical interest scale was 0.90, which indicates good reliability. The instructor's survey was adapted from the Attitudes toward problem posing (ATPP)

questionnaire from Nedaei, Radmehr, and Drake (2019). The survey includes the first six items in the ATPP questionnaire that assess individuals' enjoyment and motivation toward problem-posing. Cronbach's alpha of the ATTP questionnaire was 0.89, indicating good internal consistency.

The student interview protocol and the teacher interview protocol were also employed in the pilot study. The protocols were both semi-structured and were developed based on the general guide from Bryman (2016) so there were enough flexibility for the researcher to alter the order of questions being asked and utilize follow-up questions based on the interviewee's response along the way. The student interview protocol covered these aspects: background information, students' dispositions toward problem-posing, and students' experience during this online walkSTEM program. The instructor interview protocol covered the teaching/tutoring background, the walkSTEM and problem-posing experience before the program, the planning procedures, students' behavior during the meetings, and impacts on future instructions.

As suggested above, the procedural fluency, conceptual understanding, and problem-solving items were selected from TIMSS 2011 grade 8 mathematics assessment. The researcher utilized the coding manual from Dossey, McCrone, O'Sullivan, and Gonzales (2006), the description of conceptual understanding from NRC (2011), and the explanation of procedural fluency in National Research Council (2001) to categorize assessment items into the above three categories. According to Dossey et al. (2006), the problem-solving attributes include: identify variables or relationships, critically evaluate information, justify/prove solution, generalize or predict applicability, communicate solution, and integrate or synthesize information (p. 73). The interrater reliability (Scott's Generalized π) using these coding categories for TIMSS 2003 mathematics items was 0.74 in Dossey et al. (2006).

Methods of Analysis

The quantitative data for this study consisted of students' pre- and post-survey responses. The qualitative data included student work (walkSTEM video-watching form responses, #STEMlens photos, walkSTEM project, and presentations), and student and instructor interviews. This section describes the data management and data analysis methods employed in this study.

Quantitative Analysis

Scoring Procedures. To quantitatively analyze students' problem-posing performance, the student-generated problems on the pre- and post-surveys and the problems they created during the walkSTEM sessions (the problems associated with their #STEMlens photos, walkSTEM videos, and the walkSTEM stops) were scored based on content complexity. The content complexity levels of the mathematical and non-mathematical problems students generated were analyzed using the coding system from Liu et al. (2020) and Mayer, Lewis, and Hegarty (1992). In Liu et al. (2020), student-generated problems were coded using a 6-point grading scale (from 0 to 5). The coding system was originally used to only analyze mathematical problems and the Cronbach's alpha was 0.83, suggesting a good reliability level. In this current study, the rubric was adopted to include not only mathematical but also other STEM problems and the coding categories with examples are presented in Table 10 and the corresponding problem-posing prompt for these included example questions is listed in Figure 5.

The linguistic complexity scoring examples are presented in Table 11 (adapted from Mayer, Lewis & Hegarty, 1992). The interrater reliability rates for the linguistic complexity scoring rubric and the mathematical complexity rubric are 93% and 89%, respectively. Each

problem's linguistic complexity level will be scored based on the number of assignments,

relational, and conditional propositions included in the problem script.

Figure 5

Problem-Posing Prompt for Examples in Table 10

Task: Describe the mathematical ideas you see in this picture. What questions might you pose based on this picture?

Table 10

Content Complexity Scoring Examples

Category	Score	Examples
Not-relevant or incomprehensible	0	All circles together.
Relevant statement	1	This could be a probability question.
Relevant problem, but with ambiguity	2	Why were they build like that?
Relevant problem without any ambiguity	3	From just looking at the picture, how many circles can be calculated by each color?
Non-routine relevant problem without any ambiguity	4	If the real state agency wanted to renovate and deduct 10 meters in the living room to give more space to both Terrace & kitchen what will be the area of the Living room?
Non-routine relevant problem without any ambiguity; problem allows for multiple solutions	5	How does the color and space between each color make this picture pleasing to the eye?

Table 11

Linguistic Complexity Scoring Examples

Propositions	Examples
Assignment proposition	How many circles are there?
Relational proposition	Are there more warm color circles or cold color circles?
Conditional proposition	If every 1cm is 1m what is the total of the bathroom?

Multiple Regression Analysis. Multiple regression analysis was originally proposed in my dissertation proposal to explore the relationships among the problem-posing skill, problem-solving skill, mathematical dispositions, procedural fluency, and conceptual understanding (Tabachnick, 2012). The independent variables in this regression model were supposed to be problem-posing, problem-solving, procedural fluency, and conceptual understanding. The dependent variable was supposed to be mathematical disposition. The proposed multiple regression model is represented in Figure 6. The problem-posing variable in the model included observations of students' problem-posing work in the pre-survey, post-survey, walkSTEM video-watching activity, #STEMlens photos, and walkSTEM stops. The disposition variable in the model included students' responses to the mathematical disposition items in the pre- and post-surveys. The nesting of observations suggested that multilevel modeling (MLM) needed to be utilized to address the issue caused by the clustered data. MLM allows the relationship between variables to vary between higher-level units (Tabachnick, 2012). In this study, the higher-level units were individual students.

Figure 6

Proposed Multilevel Multiple Regression Model
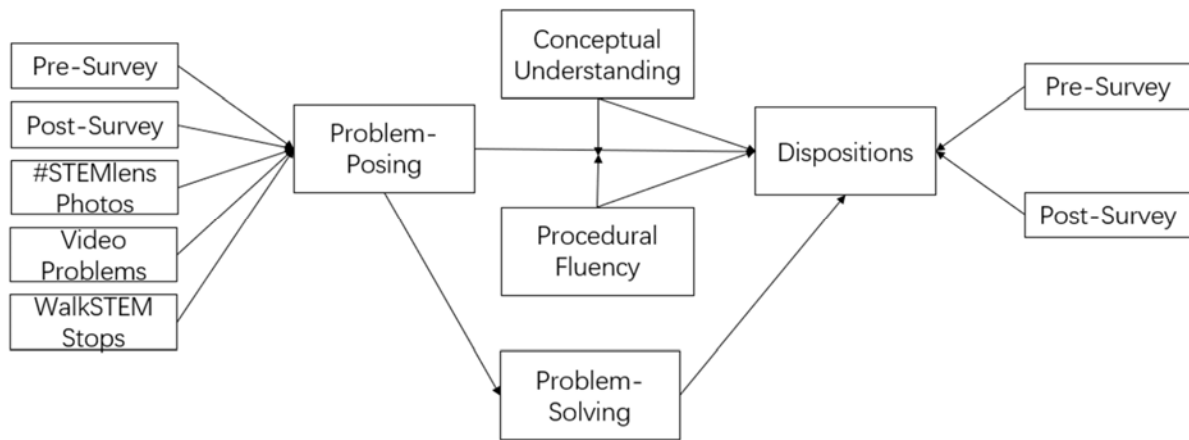
This multilevel multiple regression model was supposed to be used to analyze the main effect of problem-posing on mathematical disposition, the mediation effect of problem-solving, and the moderation effects of conceptual understanding and procedural fluency.

However, according to Maas and Hox (2005), a sample size of 50 or less at level two in multilevel modeling could generate biased standard errors estimates and lead to biased statistical analysis results. In this study, 35 students submitted the pre-survey and 18 students submitted the post-survey. This high attrition rate was mainly due to the program's online delivery format. This college preparation program was supposed to be implemented in-person and the staff would help to check in with students to maintain the attendance rate. There were also other researchers conducting studies with students in this program when students were attending in-person classes and bout 80 participants were recruited. However, with the restrictions and limitations of the online meetings, the researcher and staff were not able to effectively contact students and the participation level of students was lower than in-person meetings, which both led to a much smaller sample size than expected. This small sample size limited this study's quantitative analysis options, and the multilevel model presented above was discarded.

Paired T-Test, Fixed-Effect and Mixed-Effects Models. While the multilevel regression model proposed above was discarded, the researcher employed paired *t*-tests, one linear fixed-effect regression model, and two linear mixed-effects regression models to analyze student-generated problem's content complexity and students' dispositions before and after attending this program.

The researcher first compared students' pre- and post-survey disposition items to see if there was a significant difference in students' disposition before and after the intervention. Following the *t*-test, the researcher utilized a fixed-effects model to further investigate students' dispositions. The linear fixed-effect model used students' pre-survey disposition ratings to predict their post-survey disposition ratings while controlling for the demographic variables (i.e., gender, grade level, race, and self-reported math grade).

To investigate student-generated problems' content complexity in different problem posing activities, multiple paired *t*-tests were conducted first and Bonferroni correction was applied to correct the *p*-values. The researcher then utilized a linear mixed-effects regression model to compare students' problem-posing performance while controlling for students' pre-survey interest ratings, procedural fluency scores, conceptual understanding scores, problem-solving scores, and demographic variables (i.e., gender, grade level, race, and self-reported math grade). As the problem-posing work in different activities were nested within students, a random-effect of student ID was added in the model.

As this study also aimed to analyze the relations among students' procedural fluency, conceptual understanding, problem-solving, mathematical dispositions, and problem-posing performance, a correlational analysis and a linear mixed-effects regression model were conducted to investigate the relations. Similar to the regression model introduced above,

students' pre-survey interest ratings, procedural fluency scores, conceptual understanding scores, problem-solving scores, and demographic variables (i.e., gender, grade level, race, and self-reported math grade) were included in this mixed-effects model and a random-effect of student ID was utilized to address the multi-level data structure.

Qualitative Analysis

The qualitative analysis portion of this study employed a single case study design (Creswell, 2013) and the identified case in this study was the walkSTEM problem-posing program with the college preparation program.

Data Organizing Spiral Model. To prepare the data for analysis, the video recordings and student and teacher interviews were transcribed using the auto transcribing function from Zoom. The researcher enabled the closed captioning function on Zoom and replayed the audio and video files to get the draft transcripts. The researcher then reviewed the generated captions and modified any necessary transcripts.

All of the qualitative data were organized using the data analysis spiral model (Creswell, 2013): the researcher first organized the collected data into files and units, took reflective notes and wrote questions while reading and memoing the student work and transcripts, described, classified and interpreted the data into coding categories and themes emerged from the previous steps, and finally represented and visualized the findings using a matrix, trees, propositions, etc.

Data Coding Procedures. As suggested in the spiral model, the data coding procedures started after reading and memoing all of the collected data. Afterward, the thematic analysis was employed to identify and examine themes that emerged from the data following the six-phase procedure presented in Braun and Clarke (2006): familiarizing yourself with your data, generating initial codes, searching for themes, reviewing themes, defining and naming themes,

and producing the report. In light of the findings in the pilot studies, some potential coding foci

that the researcher paid particular attention to are listed in Table 12.

Table 12

Potential Coding Foci

Potential Coding Foci Related to Students' Problem-Posing
What topics do students focus on when they reflect on the video-watching task?
What topics do students focus on when discussing the #STEMlens photos?
What topics are their #STEMlens photos about?
What themes are mentioned when students are completing the walkSTEM planning sheet?
What topics do students focus on when creating the walkSTEM stops?
How do online tools (e.g., the gameboard, Zoom call, online searches) encourage or discourage student's participation in the program?
How do students interact with their peers?
What STEM topics/concepts are covered in their discussion, #STEMlens photos, and walkSTEM projects?
How do instructors scaffold students' problem-posing?
What resources do students use to create their STEM walk?

Reliability and Validity Evidence

In order to identify the reliable findings and results from this study, the researcher

analyzed the reliability of internal structures of the included measurements. Since the problem-

solving, conceptual understanding, and procedural fluency problems are directly adapted from

the released TIMSS assessment items, the mathematical disposition survey is adapted from

Linnenbrink-Garcia et al. (2010), and the problem-posing disposition survey is from Nedaei et al.

(2019), no additional reliability tests were performed on these test and survey items.

Regarding the two problem complexity coding systems, Cohen's kappa (Cohen, 1960)

was utilized to calculate the agreement rate between two raters. Cohen's weighted kappa was

selected because it calculates the probability when the agreement happens between two raters

and takes into account the possibility that the agreement is due to chance. For the problem-

posing test items validity evidence, to establish a strong validity for the internal structure, the objective would be to reach a Cohen's weighted kappa higher than .80, which is considered a good agreement(Landis & Koch, 1977). For this study, 54 problems were selected randomly from a total of 140 problems in 3 separate sets to be double coded by the researcher and a second-rater and the weighted kappa was .81. With respect to the linguistic complexity scoring system adapted from Mayer et al. (1992), the inter-rater reliability between the researcher and the second-rater did not meet the 0.80 Cohen's kappa threshold. The researcher compared the problems in Mayer et al. (1992) with students' problem-posing work in this study and decided to not include the scores from this linguistic complexity scoring system. The main difference was that all of students' problem-posing work in this program were based on photos, videos, or pictures and there were information in these artifacts that students used to pose problems that they did not specifically listed in the problem text. Therefore, the linguistic complexity of the problems could not be coded by only counting the number of assignments in the problem text like the way in Mayer et al. (1992). For instance, one student submitted the #STEMlens photo in Figure 7 and the question was: Assuming its lengths and widths, how much of the substance could fill its inside? If we count the assignments in this problem based on the scoring system in Mayer et al. (1992), there are 2 assignments. However, the student also gave information about the measurement of this object which makes the problems more complex than a 2-assignment problem: the height is 2 ¼ inch and the bottom diameter is 2 in. Hence, this coding system was not suitable for students' problem-posing work in this study and was not included in the following data analyses.

Figure 7

Student's #STEMlens Example

Regarding the coding procedures of the qualitative analysis, the inclusion of student work, walkSTEM meeting recordings, and student and teacher interview transcripts served as a triangulation tool in this study to enhance the credibility (Yin, 2006).

Chapter 5: Results

This study aimed to explore students' problem-posing performance in this online walkSTEM program and examined how this program shaped students' dispositions toward mathematics, problem-posing, and learning in general. The results section is organized based on the 5 research questions. Within each research question, the quantitative results are presented first, followed by the qualitative results if both quantitative and qualitative analyses are conducted to answer the question.

Descriptive Statistics

Descriptive analysis was first utilized to help the researcher to make sense of the raw data before conducting other quantitative analyses. In this section, descriptive statistics of the pre- and post-survey students' responses and student-generated problems complexity in the different problem-posing activities were presented first. Histograms of these variables were also presented to better visualize the distribution of the included data.

Students' Interest Data in Pre and Post-Survey

To understand students' dispositions, descriptive statistics (see Table 13) of the pre- and post-survey interest items and the difference between the two means were first conducted for a visual inspection: 35 students completed the pre-survey (M=3.63, SD=0.75), 18 students completed the post-survey (M=3.88, SD=0.64). The average pre-survey interest for the 17 students who completed both the pre- and post-survey was 3.74 and the standard deviation was 0.68.

Table 13

Descriptive Statistics of Students' Dispositions Toward Mathematics

Variable Name	n	M	SD
Pre-Survey Interest (all)	35	3.63	0.75
Pre-Survey Interest (with post-survey)	17	3.74	0.68
Post-Survey Interest	18	3.88	0.64
Pre to Post Difference	17	0.15	0.50

The histogram of the pre- and post-survey interest are presented in Figure 8 and the skewness statistics were -0.86, and 0.17 respectively. The pre-survey histogram is moderately negatively skewed with most of the students holding a neutral to positive disposition toward mathematics. Considering that participants were recruited from the college preparation program and all students showed up to the meeting voluntarily, this dispersion of students' initial disposition was expected. For the post-survey, fewer responses were received and there was no student with a disposition rating lower than 2.88 (from a scale of 1-5).

I first investigated whether the attrition from the program, shown by having a pre-test score but not a post-test score, was related to students' dispositions. To further understand if students who left the program were different from students who finished, the researcher conducted an independent t-test to compare the pre-survey interest scores of these two groups.

The Pre-Survey-Interest variable was transformed to achieve a skewness of -0.03 and kurtosis of -0.515. and the Shapiro-Wilk's normality test results for the two groups were not statistically significant, $p=0.93$ and $p=0.90$ retrospectively. Students who completed the program's pre-survey disposition mean ($M=3.65$, $SD=0.74$) was slightly higher than that of students who left the program ($M=3.60$, $SD=0.64$). The independent t-test result revealed that the difference in students' pre-survey dispositions was not statistically significant, $t(32)= -0.23$, 95% CI[-0.54, 0.43], $p=0.82$. In other words, there was not enough evidence that students who dropped off from the program had more negative dispositions toward mathematics and the change in the two histograms can demonstrate the change in students' dispositions in this program.

Figure 8

Histograms of Students' Disposition Toward Mathematics in Pre-Survey and Post-Survey
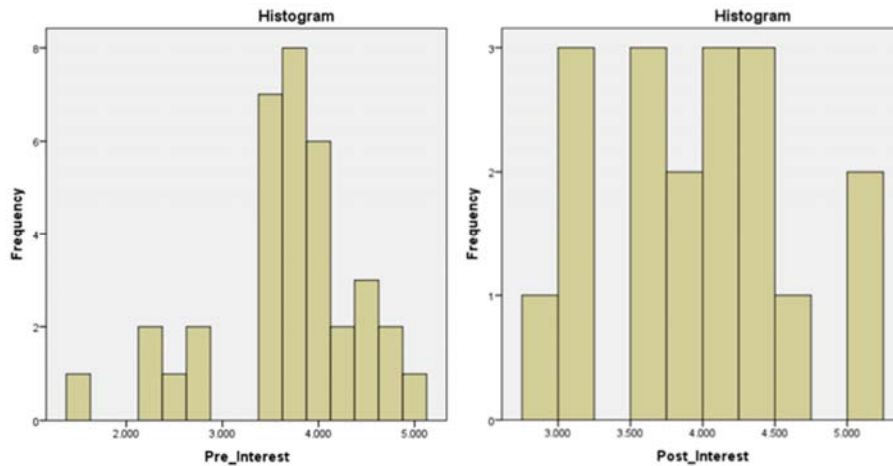
Student-Generated Problems' Complexity

Student-generated problems were coded according to the rubric adopted from Liu et al. (2020) in Table 10. Descriptive statistics of the content complexity of the problems are listed in Table 14. There were two problem-posing tasks in the pre- and post-survey and the average of the two problems' content complexity level was calculated and analyzed. On average, the pre-survey questions complexity level was at 2.77 ($SD=1.15$), which was between "Relevant

problem, but with ambiguity" and "Relevant problem without any ambiguity". Student-generated

questions' average content complexity levels were higher in all other activities compared to the

pre-survey. For the video-based problems and #STEMlens problems, depending on how many

videos students watched and how many #STEMlens photos they submitted, the researcher coded

their problems' content complexity in each video and photo. For the descriptive statistics in

Table 14, the researcher first calculated the average content complexity for each student in

video-based and #STEMlens activities and then analyzed the mean and standard deviation

accordingly. Among the different problem-posing activities students participated in, the Final

Walk problems appeared to be the most complex with an average score of 3.83 (SD=0.33), which

was between "Non-routine relevant problem without any ambiguity" and "Non-routine relevant

problem without any ambiguity, problem allows for multiple solutions". In the Final Walk

activity, students worked together in groups to create and present the walks to the audience and

each student would present one problem on the walk. According to Table 14, there were only 12

submitted problems in Final Walk, which is lower than the number of students finished the post-

survey. The reason was that some students did not submit problem to their groups' slides and

were therefore not included in the Final Walk presentation.

Table 14

Descriptive Statistics of Content Complexity of Student-Generated Problems

Variable Name	n	M	SD
Pre-Survey Content Complexity (all)	31	2.77	1.15
Pre-Survey Content Complexity (with post-survey)	16	3.28	1.03
Post-Survey Content Complexity	16	3.41	1.08
Video-based Problems Content Complexity	18	3.13	0.20
#STEMlens Content Complexity	15	3.15	0.39
Final Walk Content Complexity	12	3.83	0.33

To understand the distribution of students' problem-posing performance, histograms of these content complexity variables are listed in Figure 9. The problems' complexity levels were relatively normally distributed in the pre-survey and post-survey on the 0-5 scale, and the Skewness statistics were -.16 and -.13, respectively. The skewness statistics for problems posed after watching videos, #STEMlens photos, and the final Math walks were 0.004, 0.58, and -1.93. The most prominent observation about students' performance in these three activities was that there was no problem falling into the 0-2 range in terms of the content complexity. In other words, most of the problems were complete relevant problems (scored above 2) without any ambiguity (scored above 3).

Figure 9

Histograms of Content Complexity Levels of Student-Generated Problems
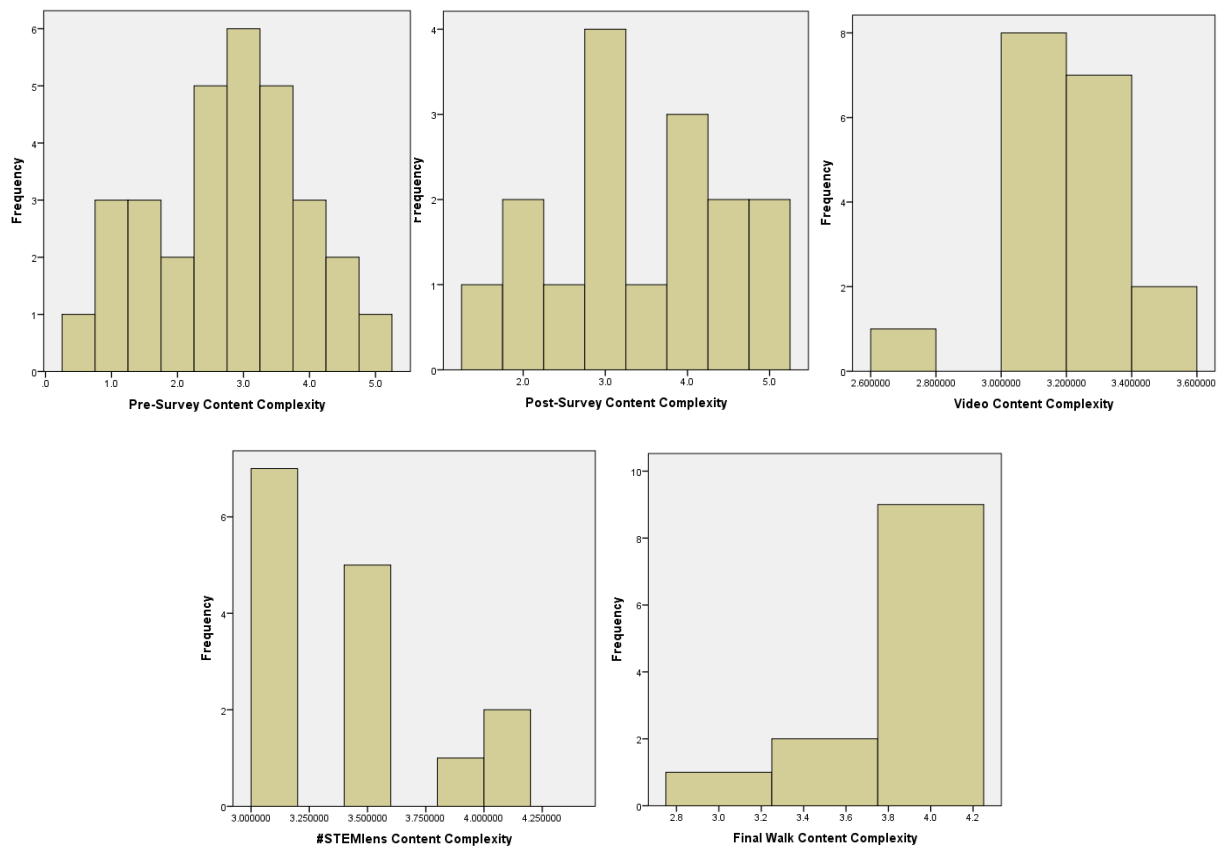
Procedural Fluency, Conceptual Understanding, and Problem-Solving Pre-Survey Scores

Students' procedural fluency, conceptual understanding, and problem-solving skills were assessed only in the pre-survey but not in the post-survey, and the researcher explained that it was not plausible to attribute students' change in these mathematical learning outcomes to the participation in the walkSTEM program. The walkSTEM program was a highly personalized experience as soon as students started to work on their #STEMlens photos and the Final Walk project since students could focus on and explore mostly any topic they were interested in. Descriptive statistics of students' procedural fluency, conceptual understanding, and problem-solving scores are listed in Table 15.

Table 15

Descriptive Statistics of Students Mathematical Learning Outcomes in Pre-Survey

Variable Name	n	M	SD
Procedural Fluency	35	2.73	1.12
Conceptual Understanding	35	2.84	.89
Problem-Solving	35	1.39	1.24

As procedural fluency, conceptual understanding, and problem-solving were graded based on the same scale and the full credit for each subarea was 4, students' scores were comparable in these subareas. According to Table 15, students' average procedural fluency (M=2.73, SD=1.12) and conceptual understanding (M=2.84, SD=.89) scores were higher than that of the problem-solving score (M=1.39, SD=1.24). To better understand the distribution of students' skills in each subarea, histograms of these three variables are presented in Figure 10.

Figure 10

Procedural Fluency, Conceptual Understanding, and Problem-Solving Scores Histograms
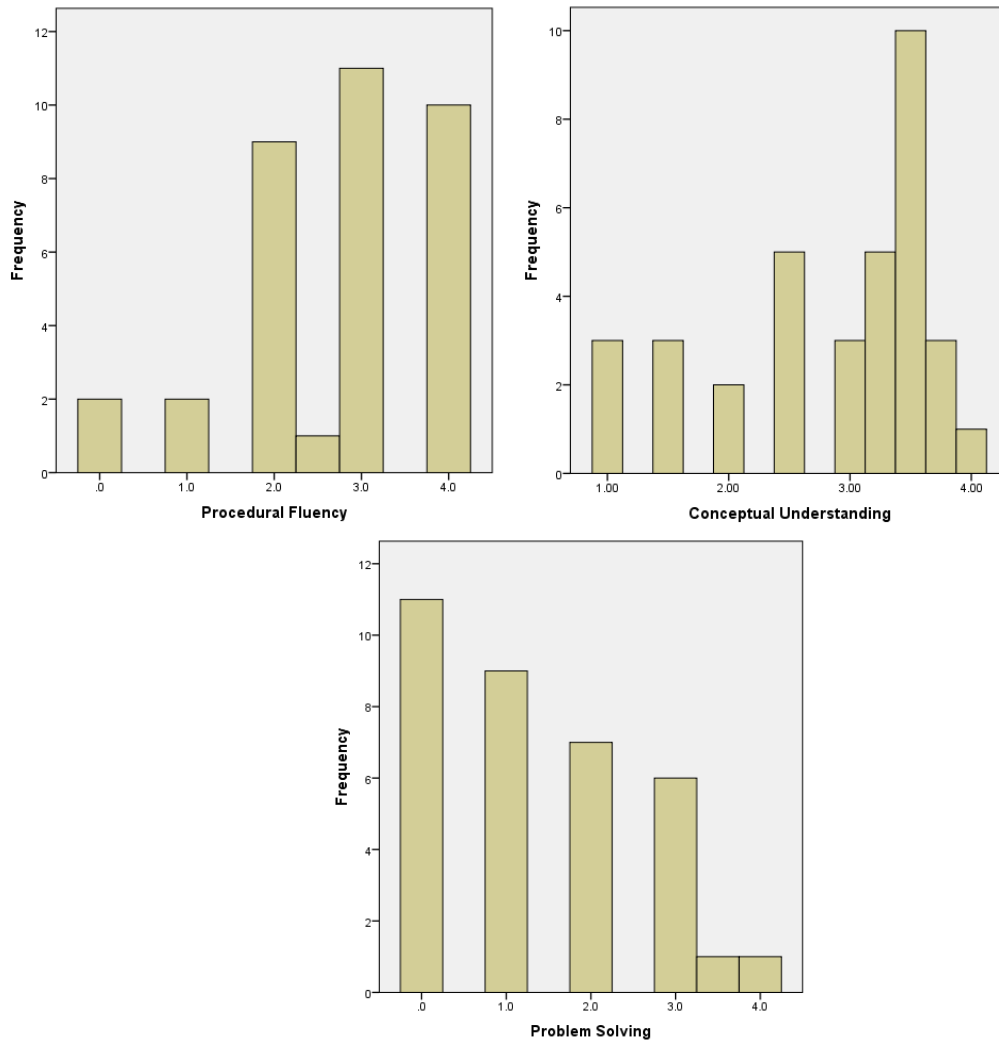
Procedural fluency and conceptual understanding were negatively skewed and the

Skewness statistics were -.75 and -.92, respectively. The Shapiro-Wilk normality test results also

suggested procedural fluency (Shapiro-Wilk statistics= .88, p=.001) and conceptual

understanding scores (Shapiro-Wilk statistics= .86, p<.0001) were not normally distributed. In

other words, more students' scores in these two subareas were higher than the averages. As

described above, there were 4 questions measured each subarea in the pretest. The histogram

indicated that there were 21 students who at least answered correctly in 3 questions in the

procedural fluency subtest. Twenty-two students answered 3 or more questions correctly in the

conceptual understanding subtest. Considering that the test items were adopted from TIMSS and

TIMSS is a test designed for 8th grade students, students' scores in procedural fluency and conceptual understanding were within the researcher's expectation.

Conversely, students' problem-solving scores distribution was positively skewed with a Skewness of .40, Shapiro-Wilk statistics of .88 (p=0.001). Given the histogram in Figure 10, 11 students scored 0, 9 students scored 1, 7 students scored 2, and 8 students scored 3 or higher in the problem-solving subtest. Compared to students' scores in procedural fluency and conceptual understanding, it was apparent that students in this program were more competent in answering questions based on known procedures than exploring potential strategies to solve unknown or uncertain mathematical contexts.

Students' Characteristics Summary

The descriptive statistics and histograms depicted students' mathematical skills from 3 perspectives before attending the program. The results for students' mathematical interest responses and their self-generated problems' content complexity levels helped the researchers understand students' characteristics more comprehensively at the baseline. Students' average response to the 8 mathematical interest items (with a 0-5 rating scale) was 3.63 (p=.75) and the Skewness statistics, -.86, indicating that the distribution was negatively skewed. The Shapiro-Wilk normality test validated that the distribution was not normal (Shapiro-Wilk statistics =.93, p=.03). Along with the histogram in Figure 9, it was apparent that the majority of the students (29 out of 35 students rated higher than 3.4 in the interest survey) in this program held more positive dispositions toward mathematical learning at the beginning. This distribution was within the researcher's expectation as students in this study were recruited from the college preparation program that students attended voluntarily.

According to students' responses in the pre-survey, there were 16 students with no prior experience in problem-posing, 5 students with problem-posing experience but not with mathematics, and 14 with some mathematical problem-posing experience. The average content complexity for the problems posed in the pre-survey problems was 2.8, SD=1.15, and the histograms in Figure 9 suggested a normal distribution. The Shapiro-Wilk statistics was 0.97 for the normality test and validated the normal distribution, p=.50. To summarize, students in this walkSTEM program were more proficient in procedural fluency and conceptual understanding when compared to their problem-solving proficiency; the majority of the students possessed positive dispositions toward mathematics learning; and students' problem-posing performance was normally distributed in the group with about 40% of the students have some prior experience in mathematical problem-posing.

Research Question 1

The first research question investigated students' dispositions toward math and problem-posing: How does designing and leading a math walk shape students' dispositions toward math and toward creating their own math problems?

Quantitative Results

A paired t-test was first employed to analyze the change in students' dispositions from pre- to post, for the 17 students who had pre- and post- data. The Shapiro-Wilk's test for the difference between pre-survey and post-survey interest mean indicated that the difference was normally distributed (p=0.91; Shapiro &Wilk, 1965). The paired t-test result revealed that the improvement in students' interest from pre-survey to post-survey, 0.15, 95%CI[-0.10, 0.41], was not statistically significant, t(16)=1.28, p=0.22.

Following the *t*-test analysis, the fixed-effect regression model was conducted to further analyze the relation between students' interest before and after the program and the results are presented in Table 16. The adjusted R^2 statistic was 0.67 which indicated that the variables included in this model explained 67% of the variance in students' post-survey interest. The regression results revealed that students' pre-survey interest was a statistically significant predictor for students' post-survey interest level and the coefficient was 0.81, *p*=0.002. The regression coefficient of Grade 11 was also statistically significant, *b*=-1.35, *p*=0.04. This fixed effect result showed that 11th graders in this program had lower mathematical disposition ratings than the 9th graders by the end of the program. The *F*-test for the entire regression model was also statistically significant, $F(9,7)=4.53$, *p*=.03, which indicated that all of the predictor variables included in this regression model were jointly significant in predicting students' post-survey interest.

Table 16

Fixed Effect Linear Regression Model Predicting Post-Survey Interest

Predictor	*b*	*SE*	95%CI	*p*-value	Sig.
(Intercept)	1.28	0.70	[-0.38,2.93]	0.11	
Pre-Survey Interest	0.81	0.17	[0.41,1.22]	0.002	**
Gender Male	-0.62	0.35	[-1.45,0.22]	0.12	
Grade 10	-0.61	0.52	[-1.85,0.62]	0.28	
Grade 11	-1.35	0.53	[-2.61,-0.1]	0.04	*
Grade 12	-0.60	0.46	[-1.69,0.49]	0.24	
Race Hispanic	0.16	0.28	[-0.52,0.83]	0.60	
Race Other	-0.07	0.45	[-1.14,1.00]	0.88	
Math Grade B	0.51	0.30	[-0.2,1.22]	0.14	
Math Grade C	-0.53	0.53	[-1.79,0.72]	0.35	

Note. Adjusted R^2=0.67, RMSE=0.24.
. indicates the correlation is significant at the .1 level (2-tailed), *p*<.1
* indicates the correlation is significant at the .05 level (2-tailed), *p*<.05
** indicates the correlation is significant at the .01 level (2-tailed), *p*<.01
*** indicates the correlation is significant at the .001 level (2-tailed), p<.0001

Qualitative Results

Following the quantitative analyses, the researcher used thematic analysis to analyze the transcripts of the post-intervention interviews and described themes that emerged from the data from two perspectives: students' disposition toward mathematics learning and students' dispositions toward the walkSTEM program.

Students' Dispositions Toward Mathematics

In the semi-structured student interviews, the prompt directly related to students' disposition toward mathematics was: How do you think your experience of creating the math walk in this program will impact your mathematical learning in the future? There were 3 themes that the researcher summarized from the qualitative coding of the transcript to this interview questions:

a) think deeper and think differently about mathematical concepts;

b) became more interested in mathematics;

c) be patient and perseverant with solving problems.

In students' interviews, the researcher interviewed 10 students who had participated in the final walkSTEM walk presentation. Even though all of the online meetings throughout the program were also reviewed and coded, the instructors spent most of the time facilitating students to complete the activities in this program instead of having general discussion about their interests in mathematics. In other words, the qualitative analysis here included more data from students who had participated in the final walk presentation and less from students who did not attend the final walk presentation.

Think deeper and think differently about mathematical concepts. The first theme emerged from students' responses was the tendency to think deeper, think differently and

sometimes think creatively. There were 8 out of 10 students brought up this theme in the post-interviews. Some examples of students' responses regarding this theme are:

> I think it's good for me because usually I would never really like thought of like this in depth questions about the different thing I did. And now I'm just like wow, I can now be able to look at something and think about it. … Being able to think about these questions about it like I really like how I was able to just think about things I never thought before.

> I think it'll make me look deeper into mathematical problems, especially like things that word problems. So I don't look over it as much and I can actually think deeper about the problem.

Students also in the interviews explained why they now would think about problems differently through the problem-posing activities. One student talked about being able to come up with questions and also solve the questions provided her a different perspective to view the problems:

> If I have friends and I think I will recommend them to program because it actually makes you think, it actually gives you a profession of yourself that you did not know. Because something as a student you just ask like, why would the teacher ask me this kind of question. And when you do this kind of project you actually understand what situation the teacher was in and why did she ask this question. Because sometimes students just think how am I supposed to response to this question, they just feel like they have to have an answer. But if you in this kind of program, I think you'll actually understand and have more, more understanding, and more clarification on questions.

The same student also described her experience with the #STEMlens photo activity to further demonstrate this new "think deeper and think differently" way of thinking:

So one of the picture I took was the picture of my window. So I think, I like the creativity because when you do when you create the question sometimes can't get that type of question. Because on the rubric it said the question has to be on the photo. But I have multiple questions, I have other things we can actually put on the thing that were kind of complicated. So I was proud of myself because that makes me think I still remember I still have that kind of … the capacity, memory, how you can interpret real-life problems … I found myself asking questions that the teacher doesn't even ask.

Per this students' description, she started to ask more questions to herself, questions that her teacher did not ask, and she was proud of herself because of this. The window #STEMlens work she described is presented below in Figure 11. The 3 problems students generated based on this photo are:

How many tables do we need to fill the whole window?

How many rows are we going to create?

How many columns are we going to create?

Figure 11

#STEMlens Activity Student Work – The Window
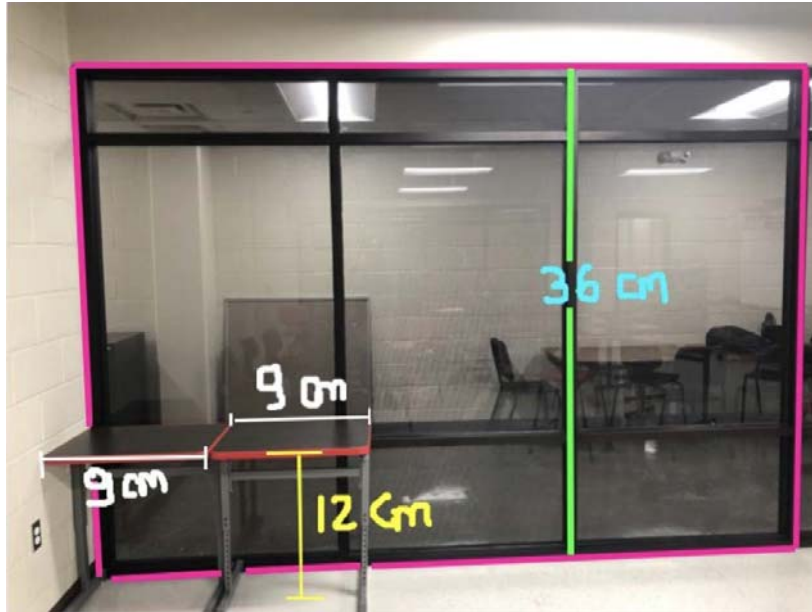
1- How many tables do we need to fill the whole window?
2- How many rows are we going to create?
3- How many columns are we going to create?

Become more interested in mathematics. Regarding students' attitudes toward

mathematics, the quantitative analysis above demonstrated that there was no statistically

significant difference between students' responses in pre-survey and post-survey. Five out of the

10 students in the post-survey talked about if their interest in mathematics changed after

attending the program, some excerpts of their responses are:

> I would say some. you know small manner like I didn't really think much in math in
>
> beginning to be honest. I guess I'm not the best at it, but when it came when it came to
>
> figuring out how big my you know, my park really was and how to convert acres to
>
> square feet in it. I did like how it does contribute a lot to what we're learning even if you
>
> don't really see it.

I think it has mm-hmm. I was interested in mathematics. I don't hate it but it definitely

has like improved. I think it's improved because now I can see math in my daily life like

just walking around

Just slightly more it's not like I really got into math or I really got into science but I really

like it increased my like interest on it. Just to think about like why doesn't it happen or

how is this related with stuff that I've learned before but I've never paying attention to it.

From students' explanations, it seemed that students developed a more positive attitude

toward mathematics and this shift in their attitudes was moderate. As I explained in the method

chapter, the various data sources served as a triangulation tool to increase the validity of the

research findings. These students' responses helped the researcher to better understand and

interpret the not statistically significant difference between students' mathematical interest scores

in pre- and post-surveys.

Be patient and perseverant with solving problems. The third theme related to students'

general mathematics dispositions was that students were more patient and perseverant when

solving mathematical problems after the intervention. In this program, students were only

required to solve their self-generated problems in the Final Walk project. In the #STEMlens, the

video-watching activity, and the pre- and post-survey, students were only asked to create the

problems. That is to say, students voluntarily chose to pose and solve problems that were more

complex and required more effort to answer in this program. The phenomenon that students

actively pursued more complex problems to solve was also evidence to support their patience

and perseverance in solving problems. In the interviews, 2 students described the problem-

solving process here as research and pointed out that it was different from the textbook problems they were used to:

> It could take a long time finding an answer for something. There's nothing that you have an answer like quick. You have to do your research you have to take your time and find in the answer most importantly because we have a lot of questions to ask but we have to have the time as well to answer the question do our research finding out what it does … because in the work that we do in school, they already have an answer. And here, we're supposed to do our research.

> It was a good experience and then I get I got to learn more about it how it really is to do a research most importantly because I think it's good … it help me like think more about how they kind of research really goes and I mean, it's not a full research. It's not a full research but I got like a glimpse of it.

> Yes, Because I think I learned more I gain more experience on how to solve stuff, having patience, because it can be hard at some point, but having patience, take it easy … we can find a solution.

Students' Dispositions Toward the walkSTEM Program

In the semi-structured student interviews, the researcher asked students which parts of the walkSTEM program they liked the most and which parts they liked the least. With the thematic analysis, activities students liked most in the program were taking pictures for #STEMlens and collaborating with peers.

Taking pictures. The activity most mentioned in students' like lists was the #STEMlens activity: 8 out of 10 students in the post-interview discussed this theme. For the #STEMlens activity, students were asked to take pictures and come up with questions about the pictures. There was no restriction on which object, place, or topic the pictures should be associated with. Some students took pictures of their surroundings (e.g., a room, a window, a water bottle, a plant). Other students went outside to take pictures at different places they liked (e.g., a park, buildings, a playground). Some examples of students talking about taking pictures are:

> Most I would say was taking the pictures maybe because it let me see how big my park really was.

> The part I like the most is that it's like interactive you can go out and explore the world. This is very interesting. We just got to show what our favorite things around the world.

Collaboration. In the theoretical framework, the importance of collaboration was summarized and peer collaboration was included in different activities of the program: students provided feedback to each other's #STEMlens pictures and questions; instructors led whole group discussions about the walkSTEM videos and questions; students worked in groups to identify a theme for their final walk presentation; and students reviewed each others' stops in the presentation and worked together to solve the problems. In the post-intervention interviews, 4 students explained their dispositions toward collaboration in this program and described how they worked together:

> The part I like the most is working with others giving ideas bouncing off ideas. We're like, "okay what about this question, we can also ask this question, oh there's a solution, we can go to this webpage to find the solution."

I like how we had to work not necessarily work together because we all did our different

stops but how we conjugated ideas together. Get onto the program and you had your

ideas already sent and then the instructor helped you like pick the ones that are like the

best ones and then also I construct better ideas.

Regarding the parts students liked the least in this program, some aspects that were

brought up frequently include: watching the walkSTEM videos and posing related questions, and

the program's online format.

Video-watching activity. The walkSTEM video-watching activity was included in the

first 5 meetings, and students were also encouraged to watch videos after class by themselves.

After watching each video, students were required to finish the video-watching form (see

Appendix C). They selected whether they liked the video and why and created other problems

related to the content in the video. Four students in the post-intervention interviews explained

that they did not enjoy the video-watching activity and most of the feedbacks were about the

time they had to spend. Students described it as "time-consuming" and "they had other school

work to do than watching the video." Another aspect that students disliked was that they were

required to pose problems based on the videos and not all of the video topics were attractive to

them. One student explained her experience with those videos:

Yeah, all right, so the videos the videos because sometimes when the person on the video

sometimes they tell and I don't really understand.

For example the problems sometimes I do have questions that don't fit the context. But.

For example if they're talking about Starbucks I have a question about Starbucks that

does not fit the context they talking about. I have to write questions that actually fit the

context. So that's the part I did not really like.

Online Program. This walkSTEM program was completely virtual and all students attended the meetings online via Zoom. This format received mixed reviews from students. According to the post-intervention interviews, there were 9 students who explained how they liked some aspects of the online meetings and there were 5 students who listed some disadvantages of the online format. Those who liked the online program indicated that it was convenient to attend the meetings, and they felt more comfortable talking through the internet than talking in person.

> I think I like it because I'm kind of a little shy and I like get a little tense when I'm like talking in person and seeing the people like staring at me and kind of like so I really like that because I didn't have to have my video on and I just felt more comfortable.

Contrarily, students who disliked the online format expressed that they preferred in-person interactions and it was especially tough at the beginning of the program to participate. Students also noticed that the attendance rate for each meeting was not ideal and they felt the participation level was lower due to the virtual meetings.

> It was a weird experience in the beginning yeah. I do enjoy it was fun so it was weird at first because it's virtual. From the beginning of March when we started online school, it was still not a good journey and especially I feel like participation has gone down to be honest because. I'm more of a visual learning than you know, typing on that. So to not be in the classroom is.

> In my group, we were like a bit more, we were 5 people … I feel like not everyone can be on the computer. For some meetings, it was only me and my friend. If we got more people, we can bounce off ideas more.

Students Dispositions Toward Problem-Posing

Followed by the analyses and findings of students' problem-posing performance, this section summarizes themes from the post-intervention interviews associated with students' disposition toward problem-posing. There are 5 themes emerged from the data:

a) it was challenging to identify problems worth exploring;

b) it was challenging to solve self-generated problems;

c) students were able to ask more questions;

d) students were able to make connections between everyday object and various subjects learned at school (e.g., STEM, Art, Humanities);

e) asking questions inspired students to think about future careers.

Challenge of Identifying Problems Worth Exploring. In the post-intervention interviews, the researcher asked students about some of their challenges when creating problems. Two main challenges emerged from students' responses: identifying problems worth exploring (7 out of 10 interviewed students) and solving self-generated problems (2 out of 10 interviewed problems). In the #STEMlens and Final Walk activities, students were provided with the rubrics in Appendix E. To receive a full score for the self-generated problems, the question had to be specific and refer to something in the photo. This criterion was not directly related to the content complexity of the problem. However, in students' problem-posing processes, they strived to create a "good question", "the one question that motivates me to learn about", and "the good question where people are gonna engage with it" which indicated that students were considering the audience when creating the problems. This theme resonated with the authentic audience effect in Crespo (2003). Students knew that they would present the Final Walk problems to their peers, instructors, and parents. As a result, they put more effort into creating the problems for the

Final Walk. The quantitative result also validated this finding. The average content complexity level of student-generated problems was the highest for the Final Walk problems (M=3.83, SD=.33), and the paired *t*-test also confirmed that students posed significantly more complicated problems in the Final Walk than in the video-watching and #STEMlens activities.

    Challenge to Solve Self-Generated Problems. The challenge to solve the problems students created was discussed four times in the student interviews. In this walkSTEM program, students were only required to solve their problems in the Final Walk project. Below is an excerpt from the post-intervention interview with Mary (S#35). She described the problem-solving process as their own research and explained why it took them longer to answer their questions.

        S#35 Mary: (The challenge is) Finding an answer. It could take a long time finding an answer for something there's nothing that you have an answer, like quick. You have to do your research, you have to take your time and finding the answer most importantly. We have a lot of questions to ask but we have to have the time as well to answer the question, do our research finding out what the answer is.

        Researcher: Do you think these problems that you ask take you longer to answer them?

        S#35 Mary: Yes because in the work that we do in school, they already have an answer. And where here, we're supposed to do our research, think about it, why is it this, and compare it, does this connect with this. That's the thing you have to do. But why I like it because we get to do our research.

    Ask more questions. Regarding the program's impact on students' problem-posing skills, besides the quantitative results discussed earlier, the qualitative analysis of students'

interviews also shed light on this topic. Seven out of the 10 interviewed students described how they could see things differently and ask questions about them after attending this program:

I just thought it was like open my eyes to like see like the different things in my environment differently and be able to like create the questions.

I think is good for me because usually I would never like thought of like this in depth questions you know, about the different things I did. And now I'm just like wow, I can now be able to look at something and think about it and come up with questions.

It will develop more like , I don't want to say IQ but I will say it will develop more my reflection on the word. Cause now I can look at something and I can ask myself why does it work like that, why isn't the other way, why this way. So I think it will open my reflection on the word more.

Make connections. With respect to problem-posing activities' impacts on students, all of the interviewed students described that they could make connections among different subject areas (e.g., STEM, Art, Humanities) and between school learned topics and real-life scenarios and objects. Some excerpts from students' interviews that covered this theme are:

Sometimes, when I'm in like in my math classes or reading the problems that are really complicated, people start asking like why do you have to do this if we're not even gonna actually use it like in real life. We would pay attention to everything, everything has math related concept. Now it's like oh that no wonder we had to learn about this when I was in school I would eventually use it at some point or another.

I started to thinking more about like STEM related questions in the world when I go out and stuff.

Because as me being Mexican, like I'm surrounded of spicy food. I think I grew up with it. I never had like the time to actually like sit down and look up the answer.

Well, most likely, because you know, there's a lot of different curriculums in school that we will think like, oh, this, this will never help us. Maybe this will give us a better understanding on what could and what wouldn't help us.

Regarding how this program influenced students' thinking about making these connections, seeing mathematics' application in their surroundings, the video-watching, #STEMlens, and Final Walk activities could be the main contributors. In the walkSTEM videos students watched, all of the objects and topics were could either be found in students' everyday lives (e.g., grocery store, swing, tree) or were based on the landmarks in the local area. Moreover, in the #STEMlens and Final walk, students were required to take pictures of their surroundings and pose questions directly related to the objects in the pictures. These three activities constantly encouraged students to see the everyday objects with a mathematical lens and connect these objects with not only mathematics but also science, technology, engineering, and the arts.

Thinking about future careers. While students started to see mathematics in their surroundings and it helped them develop a deeper understanding of the topics, 5 out of the 10 interviewed students also expressed how making these connections inspired them to think about future careers. For instance, for students in the program who wanted to be educators, they

discussed how posing problems encouraged them to view the content from the teachers'
perspectives:

> Put me in the position of the teacher the professor. And for those type of job, you need to
> actually see that you have you need to put. you need to understand what's going to
> happen if you do this or happen if you put this on that but what are you going to right
> angle here instead of acute angle mm-hmm, so yeah.

> I want to be an educator. I do want to teach math for my students. And if they doing this
> has helped me see different ways of how to open up to different ways for my students to
> see math in real world.

Additionally, students interested in other career areas indicated how the program could
help them understand the skills and knowledge needed and which school courses were essential
for different careers. For this college preparation program, students who chose to participate
expressed their willingness to apply for and attend higher education. Hence, being able to think
about their future career while exploring real-life scenarios could be especially helpful for them
to decide which career path they would like to pursue and the required courses they would need
to complete.

> Wouldn't that help with the future of being able to use what you learned from school to
> use it to learn at work?

> I want to become a math engineer or electrical engineer and for those type of job, you
> need to actually see. You need to perceive the world, you need to understand what's

going to happen if you do this. Or what will happen if you put this on that. Are you going to use right angle here instead of acute angle.

You know we all choose career. Everybody has a career that they follow up. There are courses that are core courses that we take, that are that are specifically going to are like, for whatever career. For instance, English will be for like lawyers and a bunch of other things that have to do with documents because they have to be writing those things and about their cases and everything. They have to write it explicitly in detail. While as in, let's say engineering or let's say, other scientific courses, they'll take mostly mathematics, or like from calculus and science, physics. And they'll take those classes. And sometimes they don't understand those classes, in which they'll need help on. And they, and they had to learn on their own. But if they're interested in it, they'll be learning it at home while they're learning at school, so they can make those connections.

Research Question 2

The second research question aimed to investigate students' problem-posing experiences in the program: How does designing and leading a math walk impact students' performance in posing mathematical problems? As described in the Method chapter, students were asked to pose questions about two given prompts in the pre- and post-survey and all of the students' problem-posing work were collected. The researcher first compared student-generated problems at different stages of the program quantitatively to investigate their problem-posing skills. Following the quantitative results, the researcher also reviewed and analyzed students' problem-posing procedures through the recordings of the online meetings and their post-program interviews to summarize themes and subthemes that emerged from the data.

Quantitative Results

Student-generated problems' content complexity was coded based on the rubric in Table 10. Descriptive statistics and histograms presented and discussed in the above section. Paired *t*-tests and linear mixed-effects regression models were employed to examine the differences among students' problem-posing work in different activities at different stages.

Student-Generated Problems' Content Complexity

Four paired *t*-tests were performed in this section and the Bonferroni-corrected *p* value should be 0.0125 instead of 0.5. Students' problem-posing prompts in the pre- and post-survey were the same: the art with different color circles and the floorplan in Appendix E. The Shapiro-Wilk's normality test results for the difference between pre-survey and post-survey content complexity indicated that the difference was normally distributed, *p*=0.09, which met the assumption of paired *t*-test. Paired *t*-test was then conducted and there was no statistically significant difference between the content complexity in pre- and post-survey student-generated problems, $t(15)=0.50$, *p*=0.62, 95%CI[-0.40, 0.65]. The problem-posing activities in pre- and post-survey and the walkSTEM video-watching activity are considered semi-structured problem-posing according to Stoyanova (1999) because the problem-posing prompts were provided (i.e., the figures in the pre- and post-survey and the walkSTEM videos). Because students received different prompts in the surveys and the walkSTEM videos, it could be problematic to compare the problems students generated in these activities.

In the #STEMlens activities and Final walkSTEM walk problem-posing, students were engaged in free problem-posing as they could raise questions about any topics they were interested in without much restriction. Paired *t*-tests were implemented to compare students' performance. The Shapiro-Wilk's normality test results for the difference between pre-survey

and post-survey content complexity indicated that the difference was normally distributed, $p=0.06$. The paired t-test result showed that students posed significantly more complicated problems in the Final walkSTEM walk than in #STEMlens activities, $t(9)=6.23$, $p<0.0001$, 95%CI[0.40, 0.87]. The degree of freedom for this t-test was 9 as there were 10 students who submitted at least one #STEMlens photo and presented one problem in the Final Walk.

In addition to the comparisons within each problem-posing task, analyses to compare the two types of problem-posing tasks (i.e., semi-structured and free) were also implemented. Shapiro-Wilk's normality tests were conducted first to confirm that the difference between the content complexity of video-watching problems and #STEMlens problems, and the difference between video-watching problems and Final Walk problems were both normally distributed. The Shapiro-Wilk's test results were 0.92, $df=13$, $p=0.24$, and 0.96, $df=10$, $p=0.76$ respectively. The normality test results suggested that the assumptions for paired t-tests were met. The paired t-tests were then implemented and the results revealed that there was no statistically significant difference between video-watching problems and #STEMlens problems, $t(12)=1.43$, $p=0.18$, and there was a statistically significant difference between video-watching problems and Final Walk problems, $t(9)=5.90$, $p<0.0001$. The degree of freedom for this t-test was 9 as there were 10 students who submitted at least one video-watching response and presented one problem in the Final Walk. Overall, among these three problem-posing activities students experienced in this program, students posed more content-complex problems in the Final Walk project than video-watching and #STEMlens.

Following the paired t-tests, the researcher also employed a mixed-effects model to analyze the problem complexity. Students' pre-survey interest, procedural fluency, conceptual understanding, gender, grade level, race, and self-reported math grade were included in the

model as fixed effects and the student ID was included as a random effect to account for the nested data structure.

The mixed-effects regression model results are presented in Table 17, Table 18, Table 19, Table 20, and Table 21. The adjusted R^2 statistic was 0.56 which indicated that the variables included in this model explained 56% of the variance in students' problem complexity.

In Table 17, the reference group was students' video-watching activity problems. The regression results showed how students' problem-posing performance in other activities compared to the video-watching activity. The results revealed that #STEMlens problems were more complex that video-watching problems, $b=0.33$, $p=0.02$, Cohen's $d=0.37SD$. Final Walk problems were more complex than video-watching problems, $b=0.87$, $p<0.0001$, Cohen's $d=1.10SD$. Pre-survey problems were less complex than video-watching problems, $b=-0.38$, $p=0.02$, Cohen's $d=0.43SD$.

Table 17

Mixed-Effects Linear Regression Model Comparing Problems' Complexity – Video-Watching as Reference Group

Random Effect	Variance	SD			
Student ID	0.35	0.59			
Fixed Effects	B	SE	95%CI	p-value	Sig.
(Intercept)	1.03	1.36	[-1.65,3.7]	0.46	
#STEMlens	0.33	0.14	[0.06,0.61]	0.02	*
Final Walk	0.87	0.16	[0.56,1.18]	<0.0001	***
Post-Survey	0.07	0.20	[-0.31,0.45]	0.73	
Pre-Survey	-0.38	0.16	[-0.7,-0.06]	0.02	*
Pre-Survey Interest	0.19	0.26	[-0.32,0.7]	0.47	
Procedural Fluency	0.04	0.15	[-0.26,0.33]	0.82	
Conceptual Understanding	0.46	0.22	[0.02,0.9]	0.05	.
Problem-Solving	0.07	0.17	[-0.26,0.41]	0.67	
Gender Male	-0.87	0.36	[-1.57,-0.17]	0.03	*
10th Grade	0.17	0.74	[-1.28,1.61]	0.82	
11th Grade	-0.33	0.78	[-1.86,1.19]	0.68	
12th Grade	-0.20	0.68	[-1.53,1.12]	0.77	
Race Hispanic	-0.39	0.36	[-1.1,0.31]	0.29	

Race Other	-0.24	0.64	[-1.49,1.01]	0.71
Math Grade B	0.38	0.36	[-0.32,1.08]	0.31
Math Grade C	-1.30	0.80	[-2.86,0.27]	0.13

Note. Adjusted R^2=0.56, RMSE=0.67.
. indicates the correlation is significant at the .1 level (2-tailed), $p<.1$
* indicates the correlation is significant at the .05 level (2-tailed), $p<.05$
** indicates the correlation is significant at the .01 level (2-tailed), $p<.01$
*** indicates the correlation is significant at the .001 level (2-tailed), p<.001

In Table 18, the reference group was students' #STEMlens problems. The regression results showed that #STEMlens problems were more complex than video-watching problems, b=-0.33, p=0.02, Cohen's d=0.37SD. #STEMlens problems, b=0.54, p=0.004, Cohen's d=0.63SD. Pre-survey problems were less complex than #STEMlens problems, b=-0.72, p=0.0002, Cohen's d=0.85SD.

Table 18

Mixed-Effects Linear Regression Model Comparing Problems' Complexity – #STEMlens as Reference Group

Random Effect	*Variance*	SD			
Student ID	0.35	0.59			
Fixed Effects	*B*	*SE*	95%CI	*p*-value	Sig.
(Intercept)	1.36	1.37	[-1.32,4.04]	0.34	
Video-Watching	-0.33	0.14	[-0.61,-0.06]	0.02	*
Final Walk	0.54	0.19	[0.17,0.9]	0.004	**
Post-Survey	-0.27	0.22	[-0.7,0.16]	0.23	
Pre-Survey	-0.72	0.19	[-1.09,-0.34]	0.0002	***
Pre-Survey Interest	0.19	0.26	[-0.32,0.7]	0.47	
Procedural Fluency	0.04	0.15	[-0.26,0.33]	0.82	
Conceptual Understanding	0.46	0.22	[0.02,0.9]	0.05	.
Problem-Solving	0.07	0.17	[-0.26,0.41]	0.67	
Gender Male	-0.87	0.36	[-1.57,-0.17]	0.03	*
10th Grade	0.17	0.74	[-1.28,1.61]	0.82	
11th Grade	-0.33	0.78	[-1.86,1.19]	0.68	
12th Grade	-0.20	0.68	[-1.53,1.12]	0.77	
Race Hispanic	-0.39	0.36	[-1.1,0.31]	0.29	
Race Other	-0.24	0.64	[-1.49,1.01]	0.71	
Math Grade B	0.38	0.36	[-0.32,1.08]	0.31	
Math Grade C	-1.30	0.80	[-2.86,0.27]	0.13	

Note. Adjusted R^2=0.56, RMSE=0.67.

. indicates the correlation is significant at the .1 level (2-tailed), $p<.1$
* indicates the correlation is significant at the .05 level (2-tailed), $p<.05$
** indicates the correlation is significant at the .01 level (2-tailed), $p<.01$
*** indicates the correlation is significant at the .001 level (2-tailed), p<.001

In Table 19, the reference group in this regression was students' Final Walk problems

and the results showed that Final Walk problems were more complex than #STEMlens ($b=-0.54$,

$p=0.004$, Cohen's $d=0.63SD$), Video-Watching ($b=-0.87$, $p<0.0001$, Cohen's $d=1.10SD$), Post-

Survey ($b=-0.80$, $p=0.0004$), and Pre-Survey problems ($b=-1.25$, $p<0.0001$, Cohen's $d=1.75SD$).

Table 19

Mixed-Effects Linear Regression Model Comparing Problems' Complexity – Final Walk as

Reference Group

Random Effect	*Variance*	SD			
Student ID	0.35	0.59			
Fixed Effects	*B*	*SE*	95%CI	*p*-value	Sig.
(Intercept)	1.90	1.38	[-0.80,4.59]	0.19	
#STEMlens	-0.54	0.19	[-0.9,-0.17]	0.004	**
Video-Watching	-0.87	0.16	[-1.18,-0.56]	<0.0001	***
Post-Survey	-0.80	0.22	[-1.24,-0.36]	0.0004	***
Pre-Survey	-1.25	0.19	[-1.63,-0.87]	<0.0001	***
Pre-Survey Interest	0.19	0.26	[-0.32,0.7]	0.47	
Procedural Fluency	0.04	0.15	[-0.26,0.33]	0.82	
Conceptual Understanding	0.46	0.22	[0.02,0.9]	0.05	.
Problem-Solving	0.07	0.17	[-0.26,0.41]	0.67	
Gender Male	-0.87	0.36	[-1.57,-0.17]	0.03	*
10th Grade	0.17	0.74	[-1.28,1.61]	0.82	
11th Grade	-0.33	0.78	[-1.86,1.19]	0.68	
12th Grade	-0.20	0.68	[-1.53,1.12]	0.77	
Race Hispanic	-0.39	0.36	[-1.1,0.31]	0.29	
Race Other	-0.24	0.64	[-1.49,1.01]	0.71	
Math Grade B	0.38	0.36	[-0.32,1.08]	0.31	
Math Grade C	-1.30	0.80	[-2.86,0.27]	0.13	

Note. Adjusted $R^2=0.56$, RMSE=0.67.
. indicates the correlation is significant at the .1 level (2-tailed), $p<.1$
* indicates the correlation is significant at the .05 level (2-tailed), $p<.05$
** indicates the correlation is significant at the .01 level (2-tailed), $p<.01$
*** indicates the correlation is significant at the .001 level (2-tailed), p<.001

In Table 20, the reference group in this regression was students' pre-survey problems and the results showed that pre-survey problems were less complex than Final Walk ($b=1.25$, $p<0.001$, Cohen's $d=1.75SD$), #STEMlens ($b=0.72$, $p=0.0002$, Cohen's $d=0.85SD$), Video-Watching ($b=0.38$, $p=0.02$, Cohen's $d=0.43SD$), and Post-Survey ($b=0.45$, $p=0.047$, Cohen's $d=0.51SD$).

Table 20

Mixed-Effects Linear Regression Model Comparing Problems' Complexity – Pre-Survey as Reference Group

Random Effect	Variance	SD			
Student ID	0.35	0.59			
Fixed Effects	B	SE	95%CI	p-value	Sig.
(Intercept)	0.64	1.37	[-2.03,3.32]	0.64	
Final Walk	1.25	0.19	[0.87,1.63]	<0.0001	***
#STEMlens	0.72	0.19	[0.34,1.09]	0.0002	***
Video-Watching	0.38	0.16	[0.06,0.7]	0.02	*
Post-Survey	0.45	0.22	[0.01,0.89]	0.047	*
Pre-Survey Interest	0.19	0.26	[-0.32,0.7]	0.47	
Procedural Fluency	0.04	0.15	[-0.26,0.33]	0.82	
Conceptual Understanding	0.46	0.22	[0.02,0.9]	0.05	.
Problem-Solving	0.07	0.17	[-0.26,0.41]	0.67	
Gender Male	-0.87	0.36	[-1.57,-0.17]	0.03	*
10th Grade	0.17	0.74	[-1.28,1.61]	0.82	
11th Grade	-0.33	0.78	[-1.86,1.19]	0.68	
12th Grade	-0.20	0.68	[-1.53,1.12]	0.77	
Race Hispanic	-0.39	0.36	[-1.1,0.31]	0.29	
Race Other	-0.24	0.64	[-1.49,1.01]	0.71	
Math Grade B	0.38	0.36	[-0.32,1.08]	0.31	
Math Grade C	-1.30	0.80	[-2.86,0.27]	0.13	

Note. Adjusted $R^2=0.56$, RMSE=0.67.
. indicates the correlation is significant at the .1 level (2-tailed), $p<.1$
* indicates the correlation is significant at the .05 level (2-tailed), $p<.05$
** indicates the correlation is significant at the .01 level (2-tailed), $p<.01$
*** indicates the correlation is significant at the .001 level (2-tailed), p<.001

In Table 21, the reference group was students' post-survey problems. Even though the regression coefficients were already included in Table 17, 18,19, and 20, this table is still included to clearly show the comparison results. Students' post-survey problems were more

complex than pre-survey problems ($b=-0.45$, $p=0.047$, Cohen's $d=0.51SD$), and were less

complex than Final Walk problems ($b=0.80$, $p=0.0004$, Cohen's $d=0.99SD$).

Table 21

Mixed-Effects Linear Regression Model Comparing Problems' Complexity – Post-Survey as
Reference Group

Random Effect	Variance	SD			
Student ID	0.35	0.59			
Fixed Effects	B	SE	95%CI	p-value	Sig.
(Intercept)	1.09	1.38	[-1.6,3.79]	0.44	
Pre-Survey	-0.45	0.22	[-0.89,-0.01]	0.047	*
Final Walk	0.80	0.22	[0.36,1.24]	0.0004	***
#STEMlens	0.27	0.22	[-0.16,0.70]	0.23	
Video-Watching	-0.07	0.20	[-0.45,0.31]	0.73	
Pre-Survey Interest	0.19	0.26	[-0.32,0.70]	0.47	
Procedural Fluency	0.04	0.15	[-0.26,0.33]	0.82	
Conceptual Understanding	0.46	0.22	[0.02,0.90]	0.05	.
Problem-Solving	0.07	0.17	[-0.26,0.41]	0.67	
Gender Male	-0.87	0.36	[-1.57,-0.17]	0.03	*
10th Grade	0.17	0.74	[-1.28,1.61]	0.82	
11th Grade	-0.33	0.78	[-1.86,1.19]	0.68	
12th Grade	-0.20	0.68	[-1.53,1.12]	0.77	
Race Hispanic	-0.39	0.36	[-1.10,0.31]	0.29	
Race Other	-0.24	0.64	[-1.49,1.01]	0.71	
Math Grade B	0.38	0.36	[-0.32,1.08]	0.31	
Math Grade C	-1.30	0.80	[-2.86,0.27]	0.13	

Note. Adjusted $R^2=0.56$, RMSE=0.67.
. indicates the correlation is significant at the .1 level (2-tailed), $p<.1$
* indicates the correlation is significant at the .05 level (2-tailed), $p<.05$
** indicates the correlation is significant at the .01 level (2-tailed), $p<.01$
*** indicates the correlation is significant at the .001 level (2-tailed), p<.001

In conclusion, the mixed-effects regression model results and the paired t-test results

suggested that students posed the most complex problems in the Final Walk projects, followed

by the #STEMlens problems. Among the three activities students participated in during the

online program, the least complex problems were from the video-watching activity. Regarding

student-generated problems in the pre- and post-survey problems, students posed significantly

more complex problems in the post-survey than pre-survey, and the Cohen's *d* effect size was 0.51 *SD*. The pre-survey problems were also the least complex problems among all student-generated problems in this program.

In the regressions analyses, demographic variables and students' procedural fluency, conceptual understanding, and problem-solving scores were also included. The regression coefficients and the *p*-values indicated that male students in the program posed statistically significant less complex problems than female students, *b*=-0.87, *p*=0.03, Cohen's *d*=1.07. Additionally, conceptual understanding scores positively predicted student-generated problems' content complexity, *b*=0.46, *p*=0.054. The *p* value suggested that conceptual understanding's regression coefficient was not statistically significant at *p*=0.05 level but was marginally significant.

Qualitative Results

To investigate students' problem-posing performance, all student work, the online meetings, and the post-intervention interviews were analyzed to capture students' problem-posing performance trajectories at different stages. In this section, I provide examples of student-generated questions, including graphs of the content complexity of the problems to supplement the interpretation of the trajectories, and summarizes the themes related to students' problem-posing procedures, the challenges they identified, and the impacts or problem-posing were discussed.

Students' Problem-Posing Work at Different Stages

Two students' problem-posing work are presented here. Gina (S#25) was a 12th grader and had no prior experience with problem-posing before the program according to her pre-survey response. Her mathematical interest rating in pre-survey was 3.75, in post-survey was 3.5, and
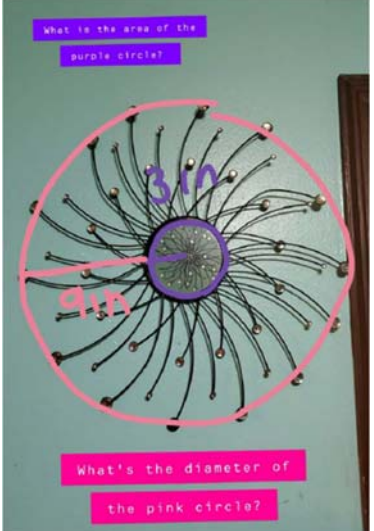
she scored 3 in procedural fluency, 3.25 in conceptual understanding, and 2 in problem-solving.

Problems Gina (S#25) created are included in Table 22. Gina (S#25) watched 5 walkSTEM

videos and submitted 1 #STEMlens photo. On average, students watched 4 videos and submitted

3 #STEMlens photos in this program. In Gina (S#25)'s problems, she posed mostly geometry

problems related to measurements in the pre- and post-surveys, walkSTEM videos, and the

#STEMlens photo. And these problems were similar to textbook problems students used to

solve. In the Final Walk project, Gina (S#25) posed a problem about pequin peppers which was

related to their walk's theme: biology and environmental science. Gina (S#25)'s Final Walk

problem appeared to be more complex and more personalized. She managed to integrate the

object she saw every day in her life to the problem she created.

Another student included here was Ellen (S#18). Ellen (S#18) was a 10th grader and had

prior problem-posing experience. His pre-survey mathematical interest rating was 2.75, his post-

survey interest rating was 3, and he scored 2 in procedural fluency, 3.5 in conceptual

understanding, and 0 in problem-solving. Ellen (S#18)'s problem-posing work is listed in Table

23. Ellen (S#18) watched 14 walkSTEM videos and submitted 19 #STEMlens photos, which

were significantly higher than the average number of videos and #STEMlens photos students

finished. The first two #STEMlens photos from Ellen (S#18) were about the radius of a circular

lamp shade and the area of a tablet. After these two photos and problems, the students posed

more complex and creative #STEMlens problems about various topics. For instance, in the tenth

#STEMlen photo Ellen (S#18) submitted, he created a problem associated with the volume of the

chip container. However, the problem did not directly ask for the volume but included more

aspects of the container, including the shape of the container, and how the shape could impact

the amount of chips compared to a box or a bag. Additionally, another phenomenon in his

#STEMlens submissions was the amount of photos and problems he was able to create in the

same environment. Ellen (S#18) took 5 #STEMlens photos and problems in his backyard, which

demonstrated how he was able to see various STEM topics and problems in the surroundings.

The 5 #STEMlens problems were #STEMlen #5 to #9 in Table 23 and were based on different

objects in the backyard: the trash can, the spider webs on tree branches, the Christmas

decorations, the wood fence, and the holes in the wood. Ellen (S#18) also covered different

topics across these 5 problems, including mathematics, environmental science, biology, and

chemistry.

Table 22

S#25 Gina's Problem-Posing Work in the Program

Activity	Problem-Posing
Pre-Survey	How many circles are in the picture? Are there more warm color circles or cold color circles? What is the total area of the bedroom?
Video-Watching	Student watched 5 videos. How much photosynthesis can a tree produce? In math, we can ask how many lines of symmetry does a figure has. When was the sun dial invented and who thought of the math behind it. Is there any symmetrical quadrilateral? Why are the traffic bollards that size?
#STEMlens	Student submitted 1 #STEMlens photo.
		#1: What is the area of the purple circle? What is the diameter of the pink circle? What is the area of the pink circle without the area of the inner circle?

Final Walk	
	Why do pequin peppers develop different colors when they come from the same plant?
Post-Survey	How many circles does the picture has? What is the area of the living room and kitchen? Which is bigger?
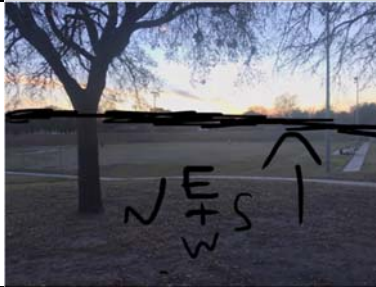
Table 23
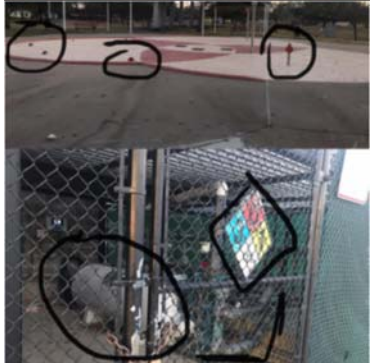
S#18 Ellen's Problem-Posing Work in the Program

Activity	Problem-Posing
Pre-Survey	From just looking at the picture, how many circles can be calculated by each color?
	What is the length of the bathroom and kitchen different from the length of the bedroom to the terrace by millimeters.
Video-Watching	Student watched 14 videos.
	How are the roots of a tree strong enough to keep it upwards?
	From my point of view how can I infer that each side of the room is exactly the same?
	What type of measurement is used to determine that each part is equal?
	What could be analyzed by what kind of material is used to hold the room together?
	If I were to be on the other side of the globe and someone else was on the opposite side, would the time be the same?
	How far must I be from the equator to have a different time stamp?
	Can each shape be measured?
	What could be the SA:V ratio of the object?
	How many toppings can I add to my drink?
	Can the amount of toppings affect the drinks proportion?
	How can temperature affect the way coffee is represented?
	If 200 cells can fit on a top of a pen, then how many cells does it take to run a whole mile?
	If the same logic stays true, can you use the graph to find out how many chapters have been read?
	What if the stadium was the same size as football stadium?
	That is one of many bridges in Dallas, can the same math be added to another bridge?

	Can any body type work with this kind of exercise?(Dance routine) Can math(algebra) be contributed to this walkSTEM as well as mechanic, considering the conveyor belt? If the measurements were off by one number could it disrupt the whole equation? How can measurements help with trying to find someone in the theater if it was crowded?
#STEMlens	Student submitted 19 #STEMlens photos.

	#1: What is the radius and/or of the diameter of this lamps circular form?
	#2: what could be the area of degree of the square-size tablet?
	#3: Which controller has a better length for holding, and which controller can give a better grip?
	#4: While in Mexico I went to one of my uncles barn. I noticed that most of the cows he had were of different color and the majority was white. Question: Why are most of the animals white and not brown? Is because of the type of breeding or the way they were from the beginning?

		#5: In the United States more than 52% of Americans do not feel the need to recycle. Question: How would the environment and our natural ecosystem be effected if more than half of the 52% of people start recycling?
		#6: In my backyard there is a huge tree, bigger than my house and I have noticed that the smaller branches are usually pulled down because of the spider webs. Question: the size of the spider's web really affect how the smaller branches are pulled? And are the spider's webbing good enough to catch prey?
		#7: For over 5 years we have had those decorations (reindeers) for Christmas. The one the left is older than the one on the right. Question: What is the cause of the rust? Is it from oxidation of being outside for so long or from old age?
		#8: From the picture I have speculated that the wooden walls in backyard are falling. Question: What would be the cause of the wood falling, metal bars have been added to support it but even so they still fall. Is there a logical explanation for the wood getting weaker?
		#9: Similar to my other stem lens, these branches have been harvested off of a dead tree. It fell from being fragile. if you Look closer you can notice that there are many small holes in the wood. Question: Can the wood have been effected by a kind of invasive species?
		#10: Can the size of the bag or box affect the amount of chips inside it? Or to be more specific can say a cylindrical shape hold more chips than a box or a bag?

		#11: It might not be the best view but when looking more into it can be very interesting. Question: Can the sides of the tunnel allow for better function if there is to much water flow?
		#12: As we know the sun falls on the east side and rises west. but have you noticed the sun has gone down sooner than usual. Question: Why has the sun be falling on 5:30pm than the original time of 8-9 pm?
		#13: Do the fans work more effectively if they are far apart from each other at a certain degree?
		#15: Since a fire extinguisher has a compound named Sodium Bicarbonate. Question: Is the dry powder inside the fire pit extinguisher compressed at a certain hold for it to be efficient when released?
		#16: does the color of the Chile have anything to do with how many nutrients it is gaining?

		#17: These are flowers that barely started blooming a couple days ago. Question: Why do these flowers start blooming now and not in spring? Does climate change have anything to say about this?
		#18: One water bottle has around 16.9 fluid ounces. Question: If someone drinks 4 water bottles a day will it be enough for the actual recommendation of 8 cups of water?
		#19: Most of the items we used in a day have wavelength and frequency. Question: What wavelength and frequency is needed for wireless headphones to work?
Final Walk		

	I wonder on why there so many things to power one small water park, and what intrigues me is how it is used, it is useful for sanitization and other reasons. How much water was possibly used daily, also from the sign shown what kind of chemicals were added to the water and for what reason?
Post-Survey	I see all of the circles on top of each other and i would ask the question of, What could the radius of all the circles, and could they all be the same? I describe this picture as a way to figure out what the size of each circle could be. What could be the radius of each circle and are they all the same? From this picture it makes me think on what could be the radius of each circle and which formula could help with that? And if each circle is the same size as each other. What could be the cm of each room of this house, and how you turn it into a m. What is the volume of the whole house by comparing each rooms size? What could be the length of the whole house considering each room of the house?

To better support the interpretation of students' different problem-posing performance, the content complexity of student-generated problems is graphed in Figure 12. The top scatterplot graph shows all students' problem complexity levels. Students posed multiple problems for the #STEMlens, video-watching, and the Final project, and the average complexity level scores were graphed. The bottom chart only includes students who participated in all five activities and the different colors of dots represent different students. Both Ellen (S#18) and Gina (S#25) are included in the bottom graph.

Figure 12

Student-Generated Problems' Content Complexity Levels in Different Problem-Posing Activities

Student-Generated Problems' Content Complexity Scatter Plot
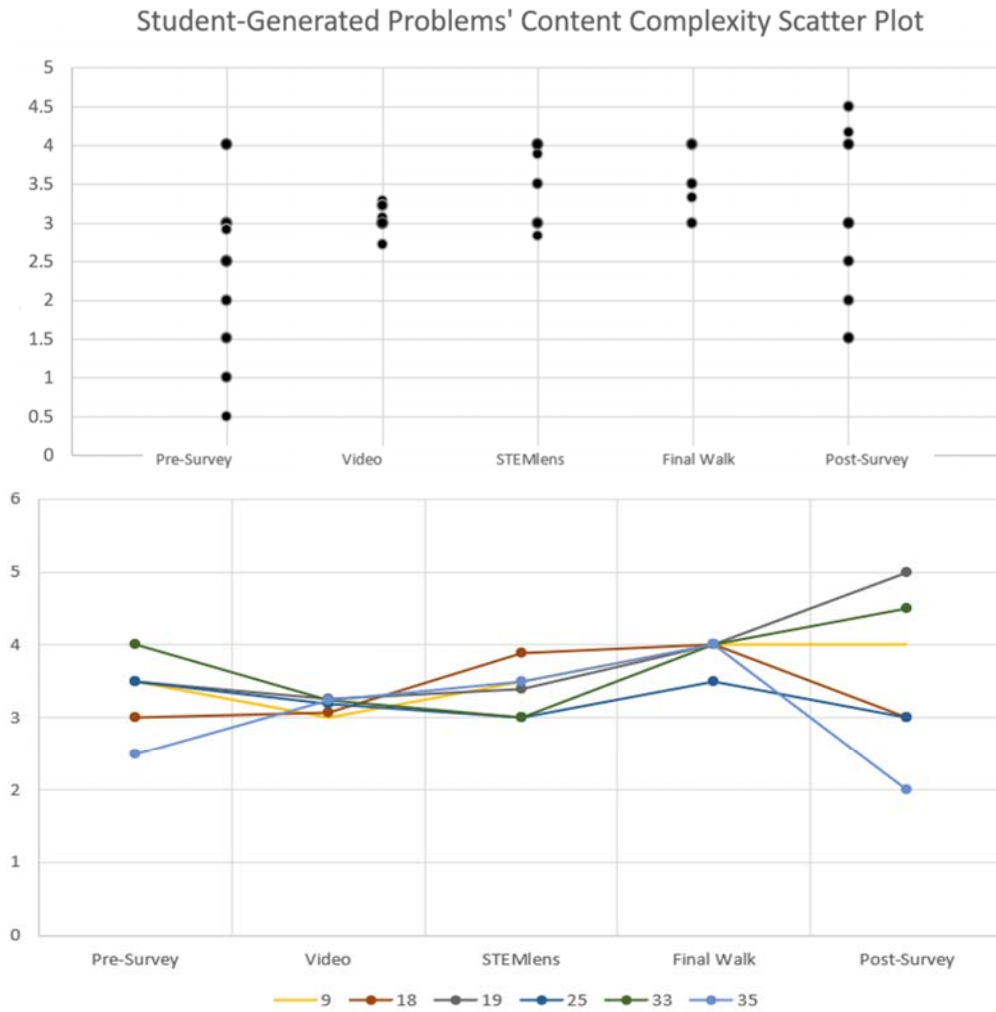
From the scatterplot and the line chart graphs, students' performance in the pre-survey

and post-survey were similar and this aligned with the descriptive statistics. There was

considerable variation in the content complexity of the student-generated problems in pre- and

post-survey. As we explained above, one potential explanation was that the prompts in the pre-

survey and post-survey were the same, which might limit the types of questions students could

generate. However, when comparing the problems in the video-watching activity, the

#STEMlens activity, and the Final walk, students posed more complicated problems as they

moved forward in the program.

Besides the limitation of the prompts in pre- and post-survey, students could work collaboratively in the #STEMlens activity and the Final Walk. In the #STEMlens activity, students took pictures and posed questions, shared work with their peers either through online submission or through screen sharing in Zoom meetings, and provided feedback by entering comments online or discussing the problems. In the Final Walk project, students created the stops together as a team, helped each other solve the problems, rehearsed the presentation, and finally presented the walk as a team. It seemed that students were engaged in more peer collaboration in the Final Walk project than when working on the #STEMlens photos. Figure 12 also indicated that students posed more complex problems in the Final Walk compared to the #STEMlens activity. Therefore, this finding contributed to the importance of peer collaboration in problem-posing.

Research Question 3

The third research question focused on the peer interactions students engaged in during their problem-posing process: What kinds of interactions do students have when they experience math walks and design their math walk questions and stops? To answer this question, the researcher analyzed students' participation during the online meetings in the program and summarized the themes that emerged as students posed problems and collaborated with their peers.

Qualitative Results

In this section, the researcher describes the procedures students used to pose problems and modify problems based on the activities' requirements and how students collaborated in different ways throughout the program. Due to the restriction posed by the online meetings, it was less convenient for students to collaborate with their peers than it would have been with in-

person meetings. During the sessions, instructors would not require students to always turn on their cameras but would encourage them to unmute and participate in discussions. However, without any small-group work or pair-work, students could only interact with each other in whole-group discussions or through online learning platforms (e.g., Canvas, shared documents).

Evaluate Peer's Problem-Posing and Provide Feedback

In the #STEMlens and the Final Walk problem-posing activities, students were asked to pose problems based on the provided rubrics (Appendix E). Once students submitted their #STEMlens photos and problems online, instructors would grade their work with the rubric. They would also guide students to reflect upon their own problems and encourage other students to provide peer feedback. Below is an excerpt from the online meetings. The instructor shared his screen and showed students' #STEMlens submissions one by one. Alan (S#14)'s submission is included in Figure 13. He evaluated his problem in the whole group discussion session based on the rubric.

> S#14 Alan: So for the question, I put, what is the angle? Because like, your angle between the point from the top to the bottom. And yeah, that was it I think. Oh, and what is the area inside of the cone because it's empty.
>
> Instructor: And then so how would you rate it? How would you rate it based on the image markup out of 5? And then how would you rate it on your question based out of 5?
>
> S#14 Alan: What was the question?
>
> Instructor: So how would you How would you rate your picture based on the rubric on the side? How would you rate your image and markup out of 5? And then how would you rate your question or observation out of 5 based on the photo that you're submitted of your birthday picture? Or birthday hat?

S#14 Alan: I will rate my question as a 4 I think. Because it is not that specific, isn't in the details. The markups, like, I think a 4 because you cannot see the image complete. Instructor: I think I agree, I think the only thing that I'd maybe suggest is kind of an indicator of how we would figure out like, what the angle is, like maybe putting like an arch over the cone saying, like, what that angle measurement is so that we can solve for the one for the cone. But other than that, yeah, I thought that was a good one.

Figure 13

Student #14 Alan's #STEMlens Photo

In the below examples, Tina (S#2) evaluated two #STEMlens photos (Figure 14) and discussed the color, the markup and the questions based on the rubric:

Figure 14

The Two #STEMlens Photos S#2 Tina Reviewed

S#2 Tina: I think that in its markups. I like the image because it's clear and beautiful. But I think maybe the markups because we don't really see. If, for example, that's the question without really knowing where to look. If maybe you have to find the perimeter of the measure or something, he or she didn't put the markup so.

S#2 Tina: I think the color, the color is kind of too dark. And also I'll say the markup too, because as a rectangle. So we don't know what the person really wants to do with two square. If he wants us to find the good diameter or something like that.

The self- and peer-evaluations students completed in this program mainly focused on the alignment to the rubrics. The rubrics talked about the quality of the photos and the markups and the connection between the problems and the photos. Even though the rubrics did not specify the

content complexity or the variety of topics in the #STEMlens photos or Final Walk project, they

served as good guidelines for problem evaluations.

Collaborate to Create Theme-Based Problems

In the #STEMlens activity, students' self- and peer-evaluation mainly focused on the

quality of the picture, if the markup is clear, and if the question is related to the picture and the

markup. For the Final Walk problems, an added layer to this project compared to #STEMlens

photos was the presence of a theme. Each group had to choose one theme, and the theme could

be a STEM topic, a place, or an interest area. Some themes selected by groups in this program

included parks, biology, basketball, and environmental science. As a result, when students

worked together in groups to create the Final Walk, they had to have discussions with each other

to make sure their problems shared the same theme. In this excerpt, the student started with a

problem more related to geometry than biology. She managed to modify her problem based on

some feedback from the group members and the instructor.

> S#8 Abby: My photo was a tree like a tree branch in the form of a triangle. And I was
>
> going to ask, what is the space between both of the branches if I'm given a squared plus b
>
> squared equals c squared?
>
> Instructor: So I guess my question to you is, would that be more related to biology or
>
> geometry with that question?
>
> S#8 Abby: Geometry.
>
> Instructor: Geometry, because you're talking about Pythagorean Theorem, a squared plus
>
> b squared plus c squared. So you kind of want to think about it in a more biological lens,
>
> if that makes sense. So other than Abby (S#8), thank you for sharing, Gina (S#25) and
>
> Nancy (S#38). Anybody? What kind of questions can we ask about a tree that is in a that

forms a triangle? What kind of questions we ask about it from a biological or

environmental science lens, rather than a lens of geometry?

S#25 Gina: Maybe why the tree took that form? Like is there something else? Like if it

got trapped between something or just why does it has that shape?

In this online program, students were not able to collaborate with each other as they

usually do in in-person meetings. Naturally, the peer collaboration rate decreased significantly as

some students did not even turn on their cameras. However, once students started to work on the

Final Walk project, they were more likely to critique each other's problems and discuss how they

could pose different problems so that their problems could be integrated in a theme-based walk.

Research Question 4

The fourth research question explored the relations between or among students' problem-

posing skills, problem-solving skills, conceptual understanding, procedural fluency, and

mathematical dispositions. In the pre-survey, students' performance in all these aspects were

assessed and were analyzed with descriptive statistics and correlational analysis. As explained in

earlier in the method chapter, the mixed-effect multilevel model was disregarded as the sample

size of this study was not large enough to yield statistically reliable results. Instead, a

correlational analysis and a mixed-effects regression model was employed to explore the

relations among these variables mentioned above.

Quantitative Results

Correlational Analysis

Pearson correlation was selected as all variables (i.e., pre-survey interest, procedural

fluency, conceptual understanding, problem-solving, and pre-survey problem-posing content

complexity) are continuous. The correlational analysis result is presented in Table 24. The *p*

values are reported in the parentheses.

Table 24

Pearson Correlation Matrix

Variable Name	1	2	3	4	5
1. Pre-Survey Interest	1				
2. Procedural Fluency	0.08 (0.67)	1			
3. Conceptual Understanding	-0.19 (0.27)	0.48^{**} (0.004)	1		
4. Problem-Solving	0.27 (0.12)	$.60^{***}$ (<0.0001)	$.50^{**}$ (0.002)	1	
5. Problem Complexity	0.45^{*} (0.01)	0.28 (0.12)	0.16 (0.38)	0.44^{*} (0.01)	1

Note. Values in the parentheses indicate the *p* value of the correlation.
* indicates the correlation is significant at the .05 level (2-tailed), *p*<.05.
** indicates the correlation is significant at the .01 level (2-tailed), *p*<.01
*** indicates the correlation is significant at the .001 level (2-tailed), *p*<.001

According to the results, the content complexity of student-generated problems was

moderately correlated with students' mathematical interest ($r(29)=0.45$, $p=0.01$) and students'

problem-solving scores ($r(29)=0.44$, $p=0.01$). This result aligned with findings in extant

literature: stronger problem-solvers also tend to be stronger problem-posers (Cai, 1998; K.-E.

Chang et al., 2012; Chen et al., 2007). However, problem complexity was not significantly

correlated with procedural fluency ($r(31)=0.28$, $p=0.12$) or conceptual understanding

($r(31)=0.16$, $p=0.38$), which means students who scored higher in the procedural fluency and

conceptual understanding problems did not necessarily pose more complex problems.

Additionally, students' procedural fluency, conceptual understanding, and problem-

solving scores were positively related to one another: conceptual understanding was moderately

correlated with procedural fluency, $r(33)=0.48$, $p=0.004$; problem-solving was strongly

correlated with procedural fluency, $r(33)=0.60$, $p<.0001$; and problem-solving was also moderately correlated with conceptual understanding, $r(33)=0.50$, $p=0.002$.

To further analyze the inter-relations, a mixed-effects regression model was employed and the regression results are presented in Table 25. Students' pre-survey interest, procedural fluency, conceptual understanding, problem-solving, and demographic variables (i.e., grade level, race, and self-reported mathematics grade) fixed effects and a random effect of student ID were included in the regression model to predict student-generated problems' content complexity. This mixed-effects model explained 59% of the variance in problem complexity. The regression coefficients indicated that conceptual understanding was a significant predictor for problem complexity, $b=0.64$, $p=0.03$. In other words, students who scored higher in the conceptual understanding subtest in pre-survey posed more complex problems in this program. However, problem-solving score ($b=0.10$, $p=0.64$) or pre-survey interest ($b=0.26$, $p=0.41$) were not significant predictors for problem complexity. Additionally, the gender fixed effect suggested that male students posed less complex problems than female students in this program which was consistent with the findings in Research Question 2 section, $b=-0.98$, $p=.03$.

Table 25

Mixed-Effects Linear Regression Model Predicting Problems' Complexity

Random Effect	*Variance*	*SD*			
Student ID	0.58	0.76			
Fixed Effects	*B*	*SE*	95%CI	*p*-value	Sig.
(Intercept)	0.46	1.67	[-1.8,3.18]	0.78	
Pre-Survey Interest	0.26	0.32	[-0.26,0.70]	0.41	
Procedural Fluency	-0.05	0.19	[-0.29,0.26]	0.79	
Conceptual Understanding	0.64	0.27	[0.16,0.99]	0.03	*
Problem-Solving	0.10	0.21	[-0.23,0.38]	0.64	
Gender Male	-0.98	0.43	[-1.56,-0.23]	0.03	*
10th Grade	0.09	0.93	[-1.16,1.42]	0.93	
11th Grade	-0.43	0.98	[-1.77,0.94]	0.67	
12th Grade	-0.18	0.86	[-1.34,1.02]	0.83	
Race Hispanic	-0.32	0.44	[-0.93,0.36]	0.47	

Race Other	-0.28	0.79	[-1.44,0.82]	0.73
Math Grade B	0.39	0.44	[-0.25,1.02]	0.38
Math Grade C	-1.21	1.00	[-2.64,0.19]	0.25

Note. Adjusted R^2=0.59, RMSE=0.72.
. indicates the correlation is significant at the .1 level (2-tailed), $p<.1$
* indicates the correlation is significant at the .05 level (2-tailed), $p<.05$
** indicates the correlation is significant at the .01 level (2-tailed), $p<.01$
*** indicates the correlation is significant at the .01 level (2-tailed), $p<.001$

In summary, student-generated problems' content complexity was correlated with their mathematical interest and problem-solving skills and conceptual understanding was a positive predictor for the content complexity.

Research Question 5

In the literature review, scaffolding strategies for problem-posing in extant studies were discussed. Some prevalent strategies included instructors providing feedback during problem-posing, students posing problems in pairs or groups, students providing peer feedback, etc. In this section, the researcher summarizes the strategies instructors in this walkSTEM program implemented to support students' problem-posing:

a) instructor model problem-posing and evaluating self-generated problems;

b) instructor provided feedback to students' problem-posing work;

c) utilizing education technology to increase students' participation level.

Qualitative Analysis

The researcher analyzed the online meeting recordings and the problem-posing work submitted by students and instructors to identify scaffolding strategies implemented in this program. Throughout the program, the instructors attended two webinars led by the researcher. For the first webinar, the researcher introduced problem-posing activities to instructors by briefly explaining the background of problem-posing in mathematics education, presenting some walkSTEM videos and #STEMlenes examples, and encouraging instructors to try out problem-

posing themselves. Before instructors' first meeting with students in this program, each

instructor had uploaded at least one #STEMlens photo along with the question(s) to the online

discussion board. The discussion board was shared with students so that they could review their

instructors' problems and make comments about the pictures or problems. For the second

webinar, the researcher introduced the Final Walk project to instructors and employed a Mursion

Simulation Environment with two teaching tasks to help instructors practice ways to scaffold

students' problem-posing. Instructors reviewed three students' #STEMlens submission and

provided them with feedback based on the #STEMlens rubric in the first teaching task. The

second teaching task presented a student's #STEMlens submission and instructors were

prompted to guide this student to expand this #STEMlens photo to an entire walk.

Instructor Modeling Problem-Posing

In this following excerpt, the instructor shared her own problem-posing work (Figure 15)

with students and talked through how she would grade her own problems using the rubric. This

instructor created three questions based on her photo and markup covering multiple subjects

including mathematics and physics. In her reflection, she talked about how she came up with the

questions, the areas she would like to touch upon with these questions (i.e., science and

mathematics), and how she could improve the quality of the markup and the clearness of the

problems. Her reflection for this photo was according to the criteria listed in the rubric in

Appendix E, which made it clear for the students the expectations of their problem-posing work.

Figure 15

Instructor's #STEMlens Photo and Questions

Questions:

What is the perimeter and area of the sign?

What scientific principle causes shadows?

Does the amount of shade change throughout the day?

Instructor: Of course. So, mine I took, I wanted to do like more of a scientific approach, as well as a math approach. So as you can see, I circled the shadows beneath two different trees, as well as the sign and then I labeled the inches of the sign. And so my question was, well, I had two questions: what scientific principle is causing the shadows from the trees? And what is the area of sign? And so if I was to rate this, I definitely would go with probably like a 4 for the image markup, because you can see that I'm only like, circling a specific part of the shadow. So if I was a student, or if I was just a viewer, I'd be like, Oh, it's like a specific part of the shadow. So it's kind of unclear. I would have liked circling the whole one, definitely something I would do for next time. I do think that you I can see pretty clearly I would maybe bold the 24 inches because it's kind of a bit faded, but you can tell. But definitely I would give that a 4. And for the observation or question, um, I would say probably a 4, because it is specific for the what is the area of the sign. Because I have the 24 inches. But the scientific principle causing the shadows

from the trees, I just don't feel like it's as specific I guess. Because it's pretty broad in what I mean by scientific principle. So I think that could have been better as well. But how do you guys rate it? Or what do you guys think? As image or observation? Any, any one of the two? What do you guys feel? Thoughts? Questions? qualms?

Instructor Providing Feedback

With respect to providing feedback to students' problem-posing work, the two approaches in this program were: grading students' #STEMlens photos on the discussion board and discussing the quality of the #STEMlens photo and Final Walk problems in whole group discussions. The Final Walk and #STEMlens rubrics are presented in Appendix E1 and Appendix E2, respectively. The rubrics included scoring guide to evaluate the quality of the photos, the clearness of the markup, and the relation between the generated problem and the #STEMlens photo. When instructors providing feedback to students, they did not only focus on the rubrics but also discussed how students' problems could be improved by including various topics and how problems could be modified to be connected to the same theme in the Final Walk.

In the first excerpt, the instructor was going through Mary (S#35)'s #STEMlens photos about a laptop (Figure 16) on the discussion board and talking about how they would grade the work based on the rubric and why. Mary (S#35)'s problem based on this photo was: What is the angle measurement of the laptop? The instructor posed two other questions based on this #STEMlens to encourage students to not only focus on Geometry but other topics: What is in a laptop that makes it that you're able to close it open and close it like that? What stops a laptop's screen from going all the way back?

Figure 16

S#35 Mary's #STEMlens Photo
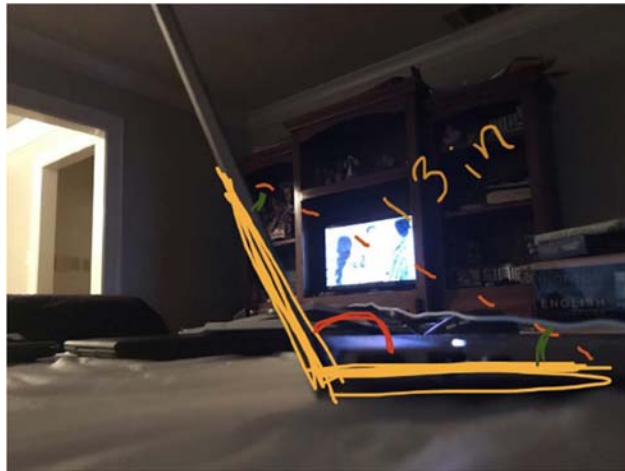
By looking at the image of the laptop, what is the angle measurement of the laptop?

Instructor: Okay, so I think 8 out of 10. Yeah, I think I would totally agree. I think that this one, I thought that the question was pretty clear. But yeah, specifying the angle that you're talking about would definitely be smart. What are some other questions we can maybe ask about Mary (S#35)'s photo? Like what I thought of, and I don't know if you guys have thought about this, like, what is in a laptop that makes it that you're able to close it open and close it like that? Like, is it a spring in there? Is it I'm just kind of like wondering, like, what's in there, that's you're able to cause they're like, what stops a laptop from going like the screen, like all the way back? That's what I kind of thought just, I mean, I don't know the answer, but I was curious about that. Just throw that out there.

Figure 17

Students' #STEMlens Problems Related to Geometry

What is the circumference of the candle top?   what could be the area of degree of the square-size tablet?

In students' #STEMlens problems, geometry was one of the most prevalent topics especially among the problems students generated in the first two online meetings. Some students' #STEMlens work with geometry questions are listed below in Figure 17. One possible explanation for this phenomenon was the problem-posing examples set by the instructors. As described earlier, the researcher led a webinar to introduce problem-posing and presented some examples. More than half of the example problems were related to measurement or shapes. When instructors were asked to create their own #STEMlens photos and problems to model problem-posing for students, 13 out of 15 problems were about angles, lengths, measurement, and shapes. When students reviewed these problems, they had no prior experience with #STEMlens and the majority of them had never participated in problem-posing activities before. Hence, it was natural for students to view instructors' problems as examples and posed similar problems. In the weekly debrief with instructors, the researcher noticed this trend in student-generated problems and discussed it with instructors. After this meeting, the instructors started to pay attention to the topics students posed problems about and encouraged them to include various topics in the problems. In the following excerpt, the instructor used her own problem

about a flower as an example and explained how she could just pose problems about things she was genuinely curious about. These explanations helped students broaden their thinking when creating problems for their #STEMlens photos and students started to pose problems bout various topics. Students' #STEMlens examples during the second half of the program are presented in Figure 18. Even though some of these problems were also associated with shapes or lengths, it was apparent that students put more thought into creating these problems. For instance, in the second #STEMlens photo in Figure 18, the student asked if the fan worked more efficiently when the fan blades were apart from each other at a certain angle. This question was considerably different from the area and perimeter problems in Figure 17.

> And I also want to make kind of like a general comment that, uh, with these STEM photos, feel free to break away from geometry and volumes and areas. Kind of asking more questions that you're just like, kind of curious about. And when I was looking at my flower, I was just kind of wondering, like, why is it like that? So kind of just, it's something that you're just even purely curious about. Yeah, I definitely encourage you guys to, and it doesn't have to be necessarily shapes. It can be artwork, and all that sort of thing. But I just wanted to put that out there.

Figure 18

Students' #STEMlens Problems of Other Topics

Which controller has a better length for holding, and which controller can give a better grip?

Do the fans work more effectively if they are far apart from each other at a certain degree?

How does the trajectory of the ball change based on the wind against the ball?

Utilizing Education Technology Tools

In this online program, education technology tools were implemented in all aspects of students' work. Students submitted their work to the Canvas learning management platform, attended all meetings through Zoom, explored different places virtually by searching for pictures and videos online, searched for strategies and answers for self-generated problems, and created presentation slides for the Final Walk. The tool that supported students the most during students' problem-posing and problem-solving was the availability of various online sources to explore and learn from. In the research question 2 section, the researcher talked about how students posed more complex problems for themselves to solve in the Final Walk. In that excerpt, Mary (S#35) described how that compared to textbook problems they used to solve, and how the problem-solving process of their Final Walk problems was more like conducting research. An example of students' problem-solving procedure using online resources is presented below. The problem students created in their group was: If the angle changes, how does this affect the distance the basketball goes in? This problem involved multiple variables, and some topics were beyond students' current knowledge. In other words, it would be difficult for this group of students to calculate the distance, the shooting angle, and the trajectory of the ball. However,

students and the instructor found an online demonstration (www.geogebra.org/m/jM3YvFaw), and they utilized it to explore the different shot angles and find the perfect angel to shoot the basketball. Students also introduced and explained the demonstration in their Final Walk presentation:

> In this demonstration, the angle is low so closer to the ground and the ball will go far in the x direction but not high in the y direction. If the angle is high, so farther up then the ball will go high in the y direction but not far in the x direction. In order for a basketball to have a good arc and make it into the basket, the angle would have to be in the middle of a very high 90 degree angle and very low 0 degree angle depending on the shooter's height.

> In summary, students were able to utilize various online resources assist their problem-posing and problem-solving procedures in the program and the availability of these resources allowed students to pose and solve more complex problems that might be beyond their current knowledge.

Chapter 6: Discussion

This study focused on understanding high school students' performance in the online problem-posing walkSTEM program and how participating in the program shaped students' mathematical learning outcomes. The discussion chapter is organized into four sections. The first section synthesizes the findings of students' problem-posing performance and discusses the implications of these results. The following two sections acknowledge the limitations of this study and some suggestions for future studies in problem-posing. Finally, the last section concisely restates the study's findings and implications.

Students' Problem-Posing Performance

Students' problem-posing performance was discussed from two perspectives: students' dispositions toward different problem-posing tasks in the program and the content complexity of student-generated problems.

Students' Dispositions Toward Problem-Posing

In this walkSTEM program, students participated in both semi-structured and free problem-posing. The pre- and post-survey and video-watching problem-posing were considered semi-structured and the #STEMlens and Final Walk problem-posing were free problem-posing according to Stoyanova (1999). Semi-structured problem-posing refers to tasks in which students generated problems based on a given problem structure or solution structure. Free problem-posing includes tasks in which students pose problems based on a mathematical operation or solution method, and tasks with no specification of the problem type or problem topic.

Among the different activities students participated in, taking pictures for #STEMlens and the Final Walk project received more positive feedback than the video-watching activity. Students suggested that taking pictures allowed them to view their surroundings from a different perspective, share things they were interested in with other students, and connect everyday objects or places to the content they learned in school classes. When introducing and discussing the #STEMlens activity, the instructors emphasized the flexibility of the objects students could talk about and repeatedly told students that there was no right or wrong answer for any of these problem-posing activities. From the Cognitive Load Theory lens (Sweller, 1988), as this activity didn't specify what the final goal (i.e., the student-generated problem) should look like and allowed students to explore any topics they were interested in, this task established lower cognitive load than the more structured problem-posing tasks which could better support students

to achieve their learning goals. In other words, students were able to devote more working memory to the problem-posing learning task itself and therefore created more complex problems.

Conversely, the part students liked the least in this program was watching the walkSTEM videos and creating problems related to the content in the videos. The two reasons students indicated were: the video-watching activity was time-consuming as they had to finish the questionnaire (Appendix D1) after each video, and the topics of students' problem-posing work were required to be related to the videos. In this program, students were not able to choose the videos to watch during the online meetings. Instead, the researcher determined which walkSTEM videos to watch and included the videos in the lesson plans that the researchers implemented. As a result, this video-watching was the least personalized activity in this program. Some students indicated that not all of the videos they were guided to watch were of interest to them, making it more difficult for them to pose problems accordingly.

In short, students preferred the free problem-posing tasks to the semi-structured problem-posing as they were allowed to explore more topics, and there were not as much constraints in the problems they posed in free problem-posing.

Content Complexity of Student-Generated Problems

Student-generated problems were coded using the content complexity coding system from Liu et al. (2020) and Maybe et al. (1992). The researcher compared student-generated problems in different activities. The results suggested that students posed the most complex problems in the Final Walk, followed by the #STEMlens problems, while the video-watching activity problems were the least complex among these three problem-posing activities students completed throughout the program. Additionally, students posed significantly more complex problems in the post-survey than pre-survey. The pre-survey problems were also the least

complex problems among all student-generated problems in this program which revealed that students were making progress in problem-posing while attending this program.

The problem-posing tasks in the pre- and post-survey and the video-watching activity were all classified as semi-structured based on Stoyanova (2003). The #STEMlens and Final Walk were free problem-posing. The more complex problems were posed in the Final Walk and #STEMlens free problem-posing projects. This finding resonated with the extant literature suggesting that integrating familiar contexts, settings, and artifacts into the problem-posing activities could promote successful problem-posing (Bonotto, 2012; English, 1997; Walkington & Bernacki, 2015).

The comparison result also indicated that even though both #STEMlens and Final Walk were free problem-posing tasks, the problems students generated in the #STEMlens activity were significantly less complicated than the Final Walk problems. The main difference between the #STEMlens and Final Walk project was the peer collaboration and the presentation. Students were able to collaborate as a group, review each other's problems, provide feedback and solve the problems together in the Final Walk. Contrarily, students mostly worked by themselves for the #STEMlens problems. Regarding the presentation of the problems, students shared the Final Walk problems they generated and discussed the answers to the problems with their peers, parents, and instructors at the end of the program through an online presentation. For the #STEMlens problems, students were just required to submit their problems to the online discussion boards. Even though the instructors encouraged students to review their peers' problems on the board and leave some comments, only two students responded and submitted comments. In addition to the scaffolds students received in these problem-posing tasks, the Final Walk also required students to solve their self-generated problems. The qualitative results

revealed that even though these problems were more difficult to solve and students tended to spend more time solving these problems than the textbook problems they were used to, they developed positive dispositions about posing and solving the problems in the Final Walk project.

In short, students tended to pose complex problems in a free problem-posing task than in a semi-structured problem-posing task. Moreover, collaborating with peers to pose and solve problems and the requirement to present the problems to the audience also were associated with more complex problems. This result provided more evidence for the authentic audience effect discussed in Crespo (2003): introducing an authentic audience (e.g., share student-generated problems with others to solve) could motivate students' active participation in problem-posing. Lastly, the comparison between students' pre- and post-survey problems validated the intervention's impact on students' problem-posing performance.

The Relations Among Student's Mathematical Learning Outcomes

This section summarizes findings from the correlational analysis and the mixed-effects regression for students' learning outcomes and their dispositions toward mathematics. The pre-survey descriptive results along with the histograms suggested that students' possessed higher procedural fluency and conceptual understanding skills than problem-solving skills at the beginning of the program. These students' characteristics aligned with the current mathematics teaching and learning circumstances. The class work focused more on teaching students the procedures to solve problems instead of finding the strategies themselves. For students' dispositions toward mathematics, as students in this study were all recruited within this existing college preparation program that students chose to attend voluntarily, it was hypothesized that students had positive dispositions toward mathematical learning before attending the online walkSTEM program. The histogram of students' pre-survey responses in the mathematical

learning interest items validated this hypothesis. Only 6 out of the 35 students rated lower than 3.4, and the average rating was 3.62 on a 0-5 scale. Lastly, the content complexity of the problems students generated in the pre-survey followed a normal distribution with the mean of 2.8 on a 0-5 scale, indicating that students did not have much prior problem-posing experience.

The correlational analysis results revealed that students' problem-posing skills were correlated with their mathematical dispositions and problem-solving skills. In other words, students who were more interested in mathematics and stronger problem-solvers also tended to be pose more complex problems. Problem complexity was not correlated with procedural fluency or conceptual understanding. Contrarily, the mixed-effects regression result revealed that problem-solving was not a significant predictor for problem complexity. Conceptual understanding was the only significant predictor in the model. One possible explanation for these mixed results could be the strong correlation between conceptual understanding and problem-solving. The correlation matrix indicated that students who were more competent in conceptual understanding tasks also scored higher in the problem-solving tasks.

Procedural fluency was not correlated with nor a significant predict for the problem complexity. According to Smith and Stein (1998), procedural fluency tasks would be categorized as procedures without connections, which means students only need to memorize the steps and procedures to find the answer to problems. Conceptual understanding, problem-posing and solving would be categorized as procedures with connections, and doing mathematics, respectively. Procedures with connections and doing mathematics tasks could help students develop deeper levels of understanding for the mathematical concepts and require students to explore and understand the nature of mathematical concepts (Smith & Stein, 1998, p.348).

Smith and Stein (1998) also categorized tasks based on the level of demands: procedural fluency tasks are lower-level demands tasks while conceptual understanding problem-posing, and problem-solving were higher-level demands tasks. These categories could explain the relations between problem-posing, problem-solving, and conceptual understanding and this finding further validated the relation between problem-posing and problem-solving mentioned in the theoretical framework. Even though there was not enough quantitative evidence that students developed more positive dispositions toward mathematics, this positive correlation between students' mathematical interest and problem-posing skills highlighted the close relation between problem-posing and mathematical disposition again. Future studies could utilize a larger-scale study to further explore how problem-posing impact students' mathematical disposition.

The walkSTEM Program's Impacts

The third section discusses how attending the walkSTEM online program shaped students' dispositions toward mathematics learning and learning in general. As the activities in this walkSTEM program were highly personalized, students could pose problems related to mathematics, science, technology, engineering, etc. Therefore, when sharing their experience in this program with the researcher, students talked about various topics including mathematics learning, their problem-solving process, future career thinking, etc.

Impacts on Students' Mathematical Learning

The paired t-test from the pre- and post-survey mathematical interest analyses suggested that there was not enough evidence that students had developed more positive dispositions after attending this program. The fixed-effects regression analysis revealed that students with higher pre-survey mathematical interest rating also were more interested in mathematics after attending the program.

One explanation for this insignificant result was the small sample size of this paired *t*-test. A recent meta-analysis calculated the average weighted effect size of students' dispositions after attending problem-posing interventions and reported an effect size of .54 (Wang, Walkington, & Rouse, under review). According to the power analysis with G*Power (Faul, Erdfelder, Buchner, & Lang, 2019; Faul, Erdfelder, Lang, & Buchner, 2007), in order to compare students' dispositions between two dependent means, the total sample size should be equal or greater than 47. However, in this study, the sample size of the paired *t*-test between pre-survey and post-survey mathematical disposition was 17, which made this analysis underpowered.

At baseline, the histogram showed that the distribution was negatively skewed, indicating that students' disposition ratings were more clustered around the distribution's right tail. In a word, students already held relatively positive dispositions toward mathematics before attending the program. As a result, there might be a potential ceiling effect and therefore the difference in students' mathematical dispositions was not statistically significant. Nevertheless, the histogram of students' mathematical dispositions in post-survey indicated that there was no student with disposition rating lower than 2.88 on a scale from 1-5 while there were 6 students rated lower than 2.75 in the pre-survey. In the post-interviews, students also indicated that their dispositions toward learning mathematics had improved but not in a significant way.

Moreover, students in the post-interviews explained how they were able to think deeper and think differently about mathematical concepts, ask more questions through a mathematical lens when looking at everyday objects in the surroundings, and be patient and perseverant with solving problems. With respect to thinking deeper and asking more questions, students started to think not only from a problem solver's perspective but also from a problem poser's perspective. In other words, students tended to think about why a particular question was raised either in the

textbook or by their teachers, what other questions they wondered about the context, and how the questions were connected to their prior learning or real-life scenarios. One student explicitly said that students usually just worried about how to respond to the question and how to find the answer to it. However, after attending this program, she could actually understand the teacher's situation and why the teacher asked this question. By putting more thought into the problems, students became active learners instead of passive learners who just followed teachers' instructions.

Regarding students' problem-solving process and dispositions, students indicated that it was challenging to identify the problems they would like to explore when posing problems. This finding indicated that students had higher expectations for their problem-posing work. There was no criterion in the rubrics in the video-watching and #STEMlens activities related to how intriguing, creative, or meaningful the problems should be. Nevertheless, students still took one step further and devoted more effort to generating problems they thought were worth exploring, showing their positive disposition toward the problem-posing tasks.

The second challenge students brought up in the post-interview was associated with solving these complex self-generated problems. Students were only asked to solve their self-generated problems in the Final Walk. This finding again validated that the problems students created for the Final Walk were of high content complexity. Students also compared this problem-solving experience with the textbook problems. They suggested that, unlike textbook problems that always have answers, they had to do their own research for the Final Walk problems and they sometimes were unsure if they would have time to answer those questions as there were too many things they did not know about the questions. Even though students thought this problem-solving process was challenging, they also indicated that they liked collaborating

with their peers to solve these problems. This process also provided them the opportunity to conduct their own research. Overall, students were aware that the problems they created for the Final Walk were more complicated and required more time and effort to solve than textbook problems but they enjoyed this problem-solving process.

Impacts on Students' Dispositions Toward Learning in General.

Besides the program's impact on students' mathematical learning and mathematical problem-posing, students also started to connect the everyday objects to the courses and topics they learned about at school. The ability and tendency to make these connections could help students develop a deeper understanding of the school curriculum. For instance, students talked about how they used to think they would never use some mathematical concepts or procedures in real-life scenarios. However, after this program, they understood why some topics were taught and how they would eventually apply that knowledge in real-world settings. Supporting students to bridge the gap between school curriculum and real-world applications has always been a challenge in STEM teaching and learning. The gap was especially challenging to address for mathematics. The activities students participated in throughout this walkSTEM program were all built upon everyday objects and real-life scenarios. Moreover, the program did not just present how these various topics were implemented in the real world but also supported students to observe the world and discover those connections themselves.

While students were providing the opportunities to explore their surroundings, they also personalized their own learning experience. For instance, some students went out to the parks in their neighborhoods to observe the fountains, the trees, and the landscape; some students found interesting objects in their houses that they would like to talk about and share with others. Throughout this process, students were also able to better express and demonstrate their cultural

identity. One example was with the problem about why and how pepper changed its color. The student explained that she created this problem as she was always surrounded by spicy food as a Mexican and she grew up with peppers.

Additionally, students' experience in this program also inspired them to think about their future careers. Even though there was no topic directly related to careers in this program, the walkSTEM videos included professionals in different fields talking about STEM-related problems in their everyday work. Students interested in pursuing a STEM career realized the importance of mathematics in their career and developed a clearer understanding of some necessary skills and knowledge needed in those STEM fields. Moreover, as discussed above, problem-posing could help students to think from a teacher's perspective. Some students also expressed how this experience made them think about how they would like to teach and how they could incorporate problem-posing into their future teaching.

Scaffolding Strategies

In this program, students who finished all activities and presented their Final Walk to the audience were all able to pose intriguing and meaningful problems with an average content complexity score of 3.83 on a 0 to 5 scale. This section summarizes the scaffolding strategies implemented in this program that supported students to improve their problem-posing performance.

Peer interaction was one of the most emphasized scaffolding strategies in the extant literature. In this program, students provided peer feedback during whole group discussions and collaborated to create the theme-based Final Walk as a group. The results section presented examples of how students reviewed each other's photos and problems and suggested other problems worth exploring based on the photos. The peer interaction levels in each activity could

be ordered this way: Final Walk > #STEMlens > video-watching. There was no peer interaction in pre- and post-survey. This order also aligned with the content complexity levels of these activities. One explanation that the peer interaction level was the highest for the Final Walk was the requirement of a theme-based walk. For each group, students had to work together to identify a theme for their walk and the stops in the walk should be related to each other. In other words, students not only had to create and solve their problems, but also were required to make sure other students in their groups posed problems with the same themes and there were connections among their problems. Naturally, students would collaborate more as they shared the same goal and were working on a group project. In the post-intervention interviews, students suggested that the participation level was lower in the program due to the online format. During the zoom meetings, many students did not turn on their cameras or microphones to participate in the whole group discussions, making it difficult for them to interact. However, the Final Walk project addressed this issue to some extent as students had to discuss and review each other's problems to make sure each problem was connected to the theme they identified. This result further validated the importance of peer interaction and collaboration in problem-posing (Gade & Blomqvist, 2015; Kontorovich et al., 2012).

Besides the peer interaction scaffolding, the instructors in the program also played an important role in supporting students' problem-posing. Instructors first modeled how to pose problems in the video-watching and #STEMlens activities. They posed their #STEMlens photos and problems to the discussion board after the first webinar they attended with the researcher and reviewed the problems with students using the rubrics. When reviewing the topics of the instructors' and students' first #STEMlens submissions, they primarily focused on geometric concepts such as the measurement, the area, and the volume. This phenomenon demonstrated

how modeling could impact an individual's problem-posing work. Before attending this program, most of the instructors and students had no prior experience with problem-posing. Therefore, when instructors noticed that the examples presented in the first webinar mainly talked about geometry, they also tended to create problems related to the same concepts. Similarly, when students viewed their instructors' problem-posing examples, they also followed the same trend and posed geometry problems accordingly. Therefore, this finding aligned with prior problem-posing studies that investigated the effect of instructor modeling (Demir, 2005; Priest, 2009; Xia et al., 2008) and provided more evidence that modeling was a powerful tool in activities such as problem-posing in which the participants did not have much experience with. At the same time, it was important to be aware of the variety of examples presented to participants when using modeling to introduce the new activity.

Once the researcher and instructors noticed the prevalence of geometry problems in students' problem-posing work, the researcher discussed this trend with instructors during the weekly debrief meetings. The instructors then encouraged students to think from perspectives other than geometry and did some modeling with students' #STEMlens photos to show the variety of problems they could ask with the pictures they submitted. In the Final Walk, only one student created a problem about the volume of a container. All of the other problems were more complicated and touched upon different concepts. For instance, in the basketball theme walk, the student's question was: How will the area of the backboard affect the person making the shot in the basket? According to the student, this problem was connected to geometry, physics, and gym activities and was much more interesting and meaningful than only asking for the backboard area. This finding validated how instructors' feedback supported students to do more in-depth problem posing.

Last but not least, the education technology tools implemented in this program were also an essential scaffold in students' problem-posing and problem-solving procedures. Students could explore various online resources to find pictures to pose problems about if they could not go out to take pictures. For instance, one student posed a problem about the hot spring and she wondered what the heating sources for the natural hot springs were. She used two pictures to show the different natural hot springs that she found online. These online recourses created more flexibility for students' problem-posing and supported them to explore mostly any topic they were interested in.

Regarding students' problem-solving procedure, an example of how students used an online demonstration to solve for the perfect angel to shoot the basketball was discussed in the results section. According to the quantitative and qualitative analysis for research question 2, among the problems students generated in different activities in this program, the Final Walk problems were the most complicated with respect to the content complexity level of the problems. In addition to the authentic audience effect discussed earlier from Crespo (2003), the availability of online resources for students to solve the problems could be another contributing reason for the more complex problems. Otherwise, considering that students were only asked to solve the problems they created for the Final Walk but not in other activities (i.e., video-watching, #STEMlens, pre-survey, post-survey), it would be understandable if they created easier to answer problems for the Final Walk project.

Limitations

The limitations of this study were discussed from three perspectives. First of all, when generalizing the research findings to other high school students or other problem-posing interventions, caution should be taken because of the delivery format, the special time of this

study, and the students' characteristics. All of the meetings in this program were delivered through virtual online meetings. According to zoom meeting recordings and students' descriptions about their experience in this program, some students were not as responsive as they were in an in-person classroom, and the instructors were not able to monitor students' behaviors conveniently. Additionally, this program was implemented during a pandemic and the majority of the students were already attending online classes all day from home. As a result, it could be difficult for students to be fully engaged in all of the activities and meetings and the instructors were not able to monitor students' learning progress. Moreover, students who participated in and completed the walkSTEM study tended to have more positive dispositions toward mathematical learning than those who left the program in the middle. Therefore, when interpreting and generalizing the research findings, these characteristics about the program implementation and students' dispositions should always be considered.

Secondly, the small sample size and the high attrition rate could threaten the internal validity of the research findings. In total, the researcher recruited 35 students participating in this program and 17 students did not finish the entire program. The sample size of 35 and the attrition rate of 48.57% could be concerning when doing quantitative analyses. As suggested above, these were the challenges and limitations caused by the online format and the special time of the program. The researcher employed this mixed-method research design and used various data sources to triangulate the findings and results to address this limitation.

Lastly, as the researcher, I am aware that my position as an international doctoral student interested in mathematics education and problem-posing would provide additional perspectives when analyzing data and interpreting results and findings in this study.

Suggestions for Future Research

This study investigated high school students' problem-posing performance and the impacts of the problem-posing program on students' mathematical dispositions and problem-posing skills with both quantitative and qualitative analyses. Even though this program was moved to online meetings due to the pandemic, the study tested and established the possibility of implementing a pure online problem-posing program. In prior studies, there were some examples of utilizing online learning modules for problem-posing interventions (Chang et al., 2012; Suarsana et al., 2019). However, the interventions usually were a combination of in-person and online experiences. Hence, this study provided future researchers with some insights about implementing a complete online problem-posing intervention. When designing and implementing online problem-posing programs, future researchers should especially pay attention to developing collaborative problem-posing activities to increase students' participation and peer interaction levels. These collaborative activities are not only effective scaffolding strategies to support students'' problem-posing but can also potentially address the high attrition issue with online interventions.

Additionally, future research should investigate the students' performance in different types of problem-posing tasks on a larger scale. As discussed in the previous chapter, students' dispositions toward free problem-posing tasks were more positive than semi-structured problem-posing and they created more complex problem in free problem-posing tasks. However, this study did not directly compare the free and semi-structured problem-posing with an experimental design. Future researcher could also conduct experimental comparisons on these problem-posing tasks to examine the differences.

From another perspective, the semi-structured problem-posing tasks in this program, the video-watching activity, provided students opportunities to see how their school curriculum was applied in different careers and inspired students to start considering which career paths they would like to pursue and what curriculums could prepare them for those careers. Moreover, the video-watching activity was also a great starting point for students to get familiarized with problem-posing as it was lower-risk and each video was an example of problem-posing. Hence, future studies should continue to explore and develop a more student-friendly, personalized, and interactive video-watching activity. For instance, future researchers can truncate the length of the video-watching form, provide different problem-posing prompts, allow students to pick videos they would like to watch and have students discuss with peers or in groups to create problems.

Conclusions

Problem-posing is the broad-based, inquiry-oriented process in which students create problems (Silver, 1994). This broad definition of problem-posing and the variance among different problem-posing interventions make it difficult for educators and researchers to interpret its effect on students' learning outcomes. For instance, there were structured, semi-structured, and free problem-posing tasks according to Sotyanova (1999). This study employed a mixed-method research design to investigate high school students' performance in semi-structured and free problem-posing tasks. The researcher explored students' dispositions toward the problem-posing activities in this program, examined the relations among students' problem-posing, procedural fluency, conceptual understanding, problem-solving, and mathematical dispositions, and identified effective scaffolding strategies that could support students' problem-posing.

The researcher implemented the walkSTEM program in an existing college preparation program and incorporated semi-structured and free problem-posing tasks in the program. The scaffolds students received included instructor modeling, instructor providing feedback for problem-

posing, peer collaboration, and educational technology tools. The semi-structured problem-posing task, video-watching, was implemented first to get students to be comfortable with problem-posing. Students then participated in #STEMlens and Final Walk activities to practice free problem-posing. The final project for students was to create the Final Walk with multiple problems connected to a theme and present the Final Walk to their peers, instructors, and parents.

The researcher collected the recordings of the online zoom meetings, students' problem-posing and problem-solving work, and students' responses in the pre- and post-survey and post-intervention interviews. The researcher analyzed the recordings and student work with both quantitative and qualitative methods: descriptive analyses and histograms for variable exploration, paired t-test to compare students' problem-posing performance in different activities, correlational analysis to reveal relations among students' procedural fluency, conceptual understanding, problem-solving, problem-posing, and mathematical dispositions, and thematic analyses to identify themes emerging from the online meetings and post-intervention interviews.

For the content complexity of student-generated problems, the result suggested that students posed more complex problems in the Final Walk than the video-watching and #STEMlens activities in this program. Students also posed more complex problems in the post-survey than in the pre-survey. Compared to the other activities, the Final Walk was a free problem-posing task and students were able to collaborate with peers to pose and solve their problems. Regarding students' mathematical dispositions, students' responses in the pre- and post-survey were investigated along with the post-intervention interviews. There was no statistically significant difference between students' mathematical interest in the pre- and post-survey. The qualitative analyses revealed that students started to think more, think deeper, ask more questions, and connect topics and content they learned about at school to everyday objects

and real-life scenarios. The researcher implemented correlational analysis to explore the relations among students' problem-posing skills, problem-solving skills, mathematical dispositions, conceptual understanding, and procedural. The correlation matrix suggested that problem-posing was positively correlated with students' mathematical interest and problem-solving skills. Finally, the online meeting recordings were employed to identify instructors' scaffolding strategies to support students' problem-posing procedures in the program: instructor modeling problem-posing, providing feedback to student-generated problems, peer collaboration, and utilizing education technology to enhance students' participation level.

In conclusion, instructors implemented scaffolding strategies such as modeling, peer collaboration and evaluation, instructor feedback, and education technology tools to support students' problem-posing in this program. This study validated problem-posing's positive effects in improving students' problem-posing skills, increasing students' mathematical learning dispositions and helping students make connections between school math and real-world applications. The study also compared the different types of problem-posing tasks and concluded that students posed more complex problems in the free problem-posing tasks and they preferred the flexibility in free problem-posing tasks.

References

Adigüzel, Ç. (2017). Exploring Mathematical Creativity In The Fractions Topic In A Fifth Grade Mathematics Class. (Master), Middle East Technical University,.

Arikan, E. E., & Unal, H. (2014). Development of the Structured Problem Posing Skills and Using Metaphoric Perceptions. *European Journal of Science and Mathematics Education, 2*, 155-166.

Arikan, E. E., & Ünal, H. (2015). Investigation of Problem-Solving and Problem-Posing Abilities of Seventh-Grade Students. *Educational Sciences: Theory and Practice, 15*, 1403-1416.

Armstrong, A. C. (2013). Problem posing as storyline: Collective authoring of mathematics by small groups of middle school students. In.

Bonotto, C. (2012). Artifacts as sources for problem-posing activities. *Educational Studies in Mathematics, 83*(1), 37-55. doi:10.1007/s10649-012-9441-7

Bonotto, C. (2013). Artifacts as sources for problem-posing activities. *Educational Studies in Mathematics, 83*, 37-55.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. doi:10.1191/1478088706qp063oa

Brown, S. I., & Walter, M. I. (1990). *The Art of Problem Posing*. Hillsdle, NF: Lawrence Erlbaum Associates Publisher.

Bryman, A. (2016). *Social research methods*: Oxford university press.

Cai, J. (1998). An Investigation of u.s. and Chinese Students' Mathematical Problem Posing and Problem Solving. *Mathematics Education Research Journal, 10*, 37-50. doi:10.1007/BF03217121

Cai, J. (2003). Singaporean students' mathematical thinking in problem solving and problem posing: an exploratory study. *International Journal of Mathematical Education in Science & Technology, 34*, 719.

Cai, J., & Hwang, S. (2002). Generalized and generative thinking in US and Chinese students' mathematical problem solving and problem posing. *21*(4), 401-421.

Cai, J., & Jiang, C. (2017). An Analysis of Problem-Posing Tasks in Chinese and US Elementary Mathematics Textbooks. *International Journal of Science & Mathematics Education, 15*, 1521-1540.

Cai, J., & Leikin, R. (2020). Affect in mathematical problem posing: conceptualization, advances, and future directions for research. *Educational Studies in Mathematics, 105*(3), 287-301. doi:10.1007/s10649-020-10008-x

Cankoy, O. (2014). Interlocked Problem Posing And Children's Problem Posing Performance In Free Structured Situations. *International Journal of Science & Mathematics Education, 12*, 219-238.

Cankoy, O., & Darbaz, S. (2010). Effect of a problem posing based problem solving instruction on understanding problem. *Hacettepe University Journal of Education, 38*, 11-24.

Chang, K.-E., Wu, L.-J. J., Weng, S.-E. E., & Sung, Y.-T. T. (2012). Embedding Game-Based Problem-Solving Phase into Problem-Posing System for Mathematics Learning. *Computers and Education, 58*, 775-786. doi:10.1016/j.compedu.2011.10.002

Chang, N. (2007). Responsibilities of a Teacher in a Harmonic Cycle of Problem Solving and Problem Posing. *Early Childhood Education Journal, 34*, 265-271.

Charles, R. I., & Lester, F. (1982). *Teaching problem solving : what, why & how*: Palo Alto, Calif. : Dale Seymour Publications.

Chen, L., Van Dooren, W., Chen, Q., & Verschaffel, L. (2007). The relationship between posing and solving arithmetic word problems among Chinese elementary school children. *Journal of the Korea Society of Mathematical Education Series D: Research in Mathematical Education, 11*(1), 1-31.

Chen, L., Van Dooren, W., & Verschaffel, L. (2013). The Relationship between Students' Problem Posing and Problem Solving Abilities and Beliefs: A Small-Scale Study with Chinese Elementary School Children. *Frontiers of Education in China, 8*, 147-161. doi:10.3868/110-002-013-0010-5

Choy, L. T. (2014). The strengths and weaknesses of research methodology: Comparison and complimentary between qualitative and quantitative approaches. *IOSR Journal of Humanities and Social Science*, *19*(4), 99-104.

Cifarelli, V. V., & Sevim, V. (2015). Problem Posing as Reformulation and Sense- Making Within Problem Solving. *Mathematical Problem Posing: From Research to Effective Practice*, 177-194. doi:10.1007/978-1-4614-6258-3

Cohen, J. (1960). A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement, 20*(1), 37-46.

Cotič, M., & Zuljan, M. V. V. (2009). Problem-Based Instruction in Mathematics and Its Impact on the Cognitive Results of the Students and on Affective-Motivational Aspects. *Educational Studies, 35*, 297-310. doi:10.1080/03055690802648085

Crespo, S. (2003). Learning to pose mathematical problems: Exploring changes in preservice teachers' practices. *Educational Studies in Mathematics, 52*(3), 243-270.

Creswell, J. W. (2013). *Qualitative inquiry & research design choosing among five approaches*. Los Angeles [etc.: Sage.

Creswell, J. W. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*: Sage publications.

Demir, B. B. (2005). *The effect of instruction with problem posing on tenth grade students' probability achievement and attitudes toward probability* (Master's thesis, Middle East Technical University).

Dickerson, V. M. (1999). *The impact of problem-posing instruction on the mathematical problem-solving achievement of seventh graders* (Doctoral dissertation, Emory University).

Dominguez, H. (2016). Mirrors & Windows into Student Noticing. *Teaching Children Mathematics, 22*, 358-365.

Dossey, J. A., McCrone, S. S., & O'Sullivan, C. (2006). Problem Solving in the PISA and TIMSS 2003 Assessments. Technical Report. NCES 2007-049. *US Department of Education*.

Ellerton, N. F. (2013). Engaging pre-service middle-school teacher-education students in mathematical problem posing: development of an active learning framework. *Educational Studies in Mathematics, 83*(1), 87-101.

English, L. D. (1997). The Development of Fifth-Grade Children's Problem-Posing Abilities. *Educational Studies in Mathematics, 34*, 183-217.

English, L. D. (1998). Children's Problem Posing within Formal and Informal Contexts. *Journal for Research in Mathematics Education, 29*, 83-106.

English, L. D., & Watson, J. M. (2015). Statistical literacy in the elementary school: Opportunities for problem posing. In *Mathematical problem posing* (pp. 241-256). Springer, New York, NY.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*

Power 3.1: Tests for correlation and regression analyses. *Behavior research methods*,

41(4), 1149-1160.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical

power analysis program for the social, behavioral, and biomedical sciences. *Behavior

research methods*, *39*(2), 175-191.

Fauziah, E. W., Hobri, Yuliati, N., & Indrawanti, D. (2019). Student's Creative Thinking Skills

in Mathematical Problem Posing Based on Lesson Study for Learning Community. *IOP

Conference Series: Earth and Environmental Science, 243*. doi:10.1088/1755-

1315/243/1/012142

Fidan, S. (2008). *The effects of problem posing activities of primary school year 5. students in

Mathematics on problem solving achievements* (Doctoral dissertation, Master

dissertation). Accessed on https://tez. yok. gov. tr).

Gade, S., & Blomqvist, C. (2015). From problem posing to posing problems via explicit

mediation in grades 4 and 5. In *Mathematical problem posing* (pp. 195-213). Springer,

New York, NY.

Guo, M., Leung, F. K. S., & Hu, X. (2020). Affective determinants of mathematical problem

posing: the case of Chinese Miao students. *Educational Studies in Mathematics, 105*(3),

367-387. doi:10.1007/s10649-020-09972-1

Guvercin, S., & Vebovskiy, V. (2014). The Effect of Problem Posing Task Used in Mathematics

Instructions to Mathematics Academic Achivement and Attitudes Toward Mathematic.

International Online Journal of Primary Education, 3(2), 59-65.

Headrick, L., Wiezel, A., Tarr, G., Zhang, X., Cullicott, C. E., Middleton, J. A., & Jansen, A. (2020). Engagement and affect patterns in high school mathematics classrooms that exhibit spontaneous problem posing: an exploratory framework and study. *Educational Studies in Mathematics*. doi:10.1007/s10649-020-09996-7

Irvine, J. (2017). Problem posing in consumer mathematics classes: Not just for future mathematicians. *The Mathematics Enthusiast, 14*, 387-412.

Kapur, M. (2015). The preparatory effects of problem solving versus problem posing on learning from instruction. *Learning & Instruction, 39*, 23-31.

Kapur, M. (2018). Examining the preparatory effects of problem generation and solution generation on learning from instruction. *Instructional Science, 46*, 61-76. doi:10.1007/s11251-017-9435-z

Karnaina, T., Bakara, M. N., Siamakania, S. Y. M., Mohammadikiaa, H., & Candrab, M. (2014). Exploring the metacognitive skills of secondary school students' use during problem posing. *Sains Humanika, 67*(1).

Kitchings, C. N. (2014). *Problem posing in middle-grades mathematics classes* (Doctoral dissertation, University of Georgia).

Kline, R. B. (2015). *Principles and practice of structural equation modeling*. Guilford publications.

Kojima, K., Miwa, K., & Matsui, T. (2015). Experimental study of learning support through examples in mathematical problem posing. *Res Pract Technol Enhanc Learn, 10*(1), 1. doi:10.1007/s41039-015-0001-5

Kontorovich, I., & Koichu, B. (2016). A case study of an expert problem poser for mathematics competitions. *International Journal of Science and Mathematics Education, 14*(1), 81-99.

Kontorovich, I., Koichu, B., Leikin, R., & Berman, A. (2012). An Exploratory Framework for Handling the Complexity of Mathematical Problem Posing in Small Groups. *Journal of Mathematical Behavior, 31*, 149-161.

Kopparla, M., Bicer, A., Vela, K., Lee, Y., Bevan, D., Kwon, H., Caldwell, C., Capraro, M. M., Capraro, R. M. (2019). The effects of problem-posing intervention types on elementary students' problem-solving. *Educational Studies, 45*(6), 708-725.d oi:10.1080/03055698.2018.1509785

Kopparla, M., & Capraro, M. M. (2018). Portrait of a Second-Grade Problem Poser. *European Journal of STEM Education, 3*.

Kotsopoulos, D., & Cordy, M. (2009). Investigating Imagination as a Cognitive Space for Learning Mathematics. *Educational Studies in Mathematics, 70*, 259-274.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *biometrics*, 159-174.

Lavigne, N. C., & Lajoie, S. P. (2007). Statistical Reasoning of Middle School Children Engaged in Survey Inquiry. *Contemporary Educational Psychology, 32*, 630-666.

Leung, S.-k. S. (2013). Teachers implementing mathematical problem posing in the classroom: challenges and strategies. *Educational Studies in Mathematics, 83*, 103-116.

Li, R., & Lü, C. (2004). The study of mathematics teaching model of "setting situations and posing problems" in middle and primary schools easing junior middle school students in Guizhou mathematics anxiety. *Journal of Mathematics Education, 4*, 88-89.

Lin, K. M., & Leng, L. W. (2008). Using problem-posing as an assessment tool. In *10th Asia-Pacific Conference on Giftedness, Singapore* (pp. 1-15).

Linnenbrink-Garcia, L., Durik, A., Conley, A., Barron, K., Tauer, J., Karabenick, S., & Harackiewicz, J. (2010). Measuring Situational Interest in Academic Domains. *Educational and Psychological Measurement - EDUC PSYCHOL MEAS, 70*, 647-671. doi:10.1177/0013164409355699

Liu, Q., Liu, J., Cai, J., & Zhang, Z. (2020). The relationship between domain- and task-specific self-efficacy and mathematical problem posing: a large-scale study of eighth-grade students in China. *Educational Studies in Mathematics, 105*(3), 407-431. doi:10.1007/s10649-020-09977-w

Lowrie, T. (2002). Young Children Posing Problems: The Influence of Teacher Intervention on the Type of Problems Children Pose. *Mathematics Education Research Journal, 14*, 87-98.

Maas, C. J. M., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *1*(3), 86-92.

Mahendra, R., Slamet, I., & Budiyono. (2017). The Effect of Problem Posing and Problem Solving with Realistic Mathematics Education Approach to The Conceptual Understanding and Adaptive Reasoning. *AIP Conference Proceedings, 1913*, 1-4.

Mayan, T. (2019). *The effect of problem solving and problem posing practices on mathematical literacy of 7th grade students.* (Master), Dokuz Eylul University,

Mayer, R. E. (1998). Cognitive, metacognitive, and motivational aspects of problem solving. *Instructional Science, 26*(1-2), 49-63.

Mayer, R. E., Lewis, A. B., & Hegarty, M. (1992). Qualitative Reasoning About Quantitative Problems.

McGraw, R., & Rubinstein-Avila, E. (2009). Middle school immigrant students developing

    mathematical reasoning in Spanish and English. *Bilingual Research Journal*, *31*(1-2),

    147-173.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching:

    Using a qualitative approach to connect homes and classrooms. *Theory into practice*,

    31(2), 132-141.

Munroe, K. L. (2016). Assessment of a problem posing task in a Jamaican grade four

    mathematics classroom. *Journal of Mathematics Education at Teachers College*, *7*(1).

National Council of Teachers of Mathematics. Commission on Professional Teaching Standards

    for School Mathematics (1992). *Professional standards for teaching mathematics*.

    Reston: National Council of Teachers of Mathematics.

National Research Council. (2001). *Adding it up: Helping children learn mathematics* (Vol.

    2101). Mathematics Learning Study Committee, Center for Education, Division of

    Behavioral and Social Sciences and Education. Washington, DC: Citeseer.

Nedaei, M., Radmehr, F., & Drake, M. (2019). Exploring Engineering Undergraduate Students'

    Attitudes toward Mathematical Problem Posing. *Journal of Professional Issues in*

    Engineering Education and Practice, 145(4).

Nivera, G. C. (2017). What happens when teachers and students are introduced to Mathematical

    Investigations: An exploratory study. *International Journal for Mathematics Teaching &*

    Learning, 18, 333-345.

Ozdemir, A. S., & Sahal, M. (2018). The effect of teaching integers through the problem posing

    approach on students' academic achievement and mathematics attitudes. *Eurasian*

    Journal of Educational Research, 2018, 117-138. doi:10.14689/ejer.2018.78.6

Panbanlame, K., Sangaroon, K., & Inprasitha, M. (2014). Students' intuition in mathematics class using lesson study and open approach. *Psychology, 5*, 1503-1516. doi:10.4236/psych.2014.513161

Pelczer, I., & Gamboa Rodríguez, F. (2011). Creativity assessment in school settings through problem posing tasks. *Montana Mathematics Enthusiast, 8*, 383-398.

Pourdavood, R. R. (2003). *Problem solving dynamics: Students' nonroutine problem solving engagement. A case study of four ninth-grade mathematics students*. The University of Oklahoma.

Priest, D. J. (2009). *A problem-posing intervention in the development of problem-solving competence of underachieving, middle-year students* (Doctoral dissertation, Queensland University of Technology).

Retnowati, E., Fathoni, Y., & Chen, O. (2018). Mathematics problem solving skill acquisition: Learning by Problem Posing or by Problem Solving? *Jurnal Cakrawala Pendidikan, 37*(1).

Salman, E. (2012). *The impact of problem posing activities in elementary mathematics instruction on students? problem solving achievement and attitudes.* (Master's thesis),

Schindler, M., & Bakker, A. (2020). Affective field during collaborative problem posing and problem solving: a case study. *Educational Studies in Mathematics, 105*(3), 303-324. doi:10.1007/s10649-020-09973-0

Shapiro, S. S., & Wilk, M. B. J. B. (1965). An analysis of variance test for normality (complete samples). *52*(3/4), 591-611.

Silver, E. A. (1994). On Mathematical Problem Posing. *For the Learning of Mathematics, 14*, 19-28.

Silver, E. A., & Cai, J. (2005). Assessing Students' Mathematical Problem Posing. *Teaching Children Mathematics, 12*, 129-135.

Singer, F., Ellerton, N., & Cai, J. (2013). Problem-posing research in mathematics education: new questions and directions. *Educational Studies in Mathematics, 83*, 1-7.

Singer, F., & Voica, C. (2013). A problem-solving conceptual framework and its implications in designing problem-posing tasks. *Educational Studies in Mathematics, 83*, 9-26.

Singer, F. M., & Voica, C. (2015). Is problem posing a tool for identifying and developing mathematical creativity?. In *Mathematical problem posing* (pp. 141-174). Springer, New York, NY.

Siswono, T. Y. E. (2010). Leveling Students' Creative Thinking in Solving and Posing Mathematical Problem. *Indonesian Mathematical Society Journal on Mathematics Education, 1*, 17-40.

Siswono, T. Y. E. (2011). Level of Student's Creative Thinking in Classroom Mathematics. *Educational Research and Reviews, 6*, 548-553.

Smith, M. S., & Stein, M. K. (1998). Reflections on practice: Selecting and creating mathematical tasks: From research to practice. *3*(5), 344-350.

Stockton, J. C. (2010). Education of Mathematically Talented Students in Hungary. *Journal of Mathematics Education at Teachers College, 1*, 1-6.

Stoyanova, E. (1999). Extending Students' Problem Solving via Problem Posing. *Australian Mathematics Teacher, 55*, 29-35.

Stoyanova, E. (2003). Extending sudents' understanding of mathematics via problem-posing. *Australian Mathematics Teacher, 59*, 32.

Suarsana, I. M., Lestari, I. A. P. D., & Mertasari, N. M. S. (2019). The Effect of Online Problem Posing on Students' Problem-Solving Abilitiy in Mathematics. *International Journal of Instruction, 12*, 809-820.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive science, 12*(2), 257-285.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Cognitive load theory in perspective. In *Cognitive load theory* (pp. 237-242). Springer, New York, NY.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. *Educational Psychology Review, 31*(2), 261-292. doi:10.1007/s10648-019-09465-5

Tabachnick, B. G. (2012). *Using multivariate statistics : international edition*. [Place of publication not identified]: Pearson.

talkSTEM. (2019). *Create Your Own walkSTEM® — Teacher Educators (Pre- & Inservice)*. Retrieved December 8, 2021, from https://talkstem.org/create-your-own-walkstem-teacher-educators/

talkSTEM. (2020). *#STEMlens as a Tool for Student Assessment*. Retrieved December 8, 2021, from https://talkstem.org/stemlens-as-a-tool-for-student-assessment/

Tanner-Smith, E. E., & Tipton, E. (2014). Robust variance estimation with dependent effect sizes: practical considerations including a software tutorial in Stata and spss. *Res Synth Methods, 5*(1), 13-30. doi:10.1002/jrsm.1091

Tofighi, D., & MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods, Instruments, & Computers, 43*(3), 692-700.

Voica, C., & Singer, F. (2013). Problem modification as a tool for detecting cognitive flexibility in school children. *ZDM, 45*, 267-279.

Voica, C., Singer, F. M., & Stan, E. (2020). How are motivation and self-efficacy interacting in problem-solving and problem-posing? *Educational Studies in Mathematics, 105*(3), 487-517. doi:10.1007/s10649-020-10005-0

Walkington, C. (2013). Using adaptive learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of educational psychology, 105*(4), 932.

Walkington, C. (2017). Design Research On Personalized Problem Posing In Algebra. *Conference Papers -- Psychology of Mathematics & Education of North America*, 195-202.

Walkington, C., & Bernacki, M. (2015). Students authoring personalized "algebra stories": Problem-posing in the context of out-of-school interests. *Journal of Mathematical Behavior, 40*, 171-191.

Walkington, C., & Hayata, C. A. (2017). Designing Learning Personalized to Students' Interests: Balancing Rich Experiences with Mathematical Goals. *ZDM: The International Journal on Mathematics Education, 49*, 519-530.

Wang, M., Rouse, A. G., & Walkington, C. (under review – Revise and Resubmit). A Meta-Analysis on the Effects of Problem-Posing in Mathematics Education. *Mathematical Thinking and Learning.*

Weber, K., Radu, I., Mueller, M., Powell, A., & Maher, C. (2010). Expanding Participation in Problem Solving in a Diverse Middle School Mathematics Classroom. *Mathematics Education Research Journal, 22*, 91-118.

Xia, X., Lü, C., & Wang, B. (2008). Research on Mathematics Instruction Experiment Based Problem Posing. *Journal of Mathematics Education, 1*(1), 153-163.

Xia, X., Lü, C., Wang, B., & Song, Y. (2007). Experimental research on mathematics teaching of "situated creation and problem-based instruction" in Chinese primary and secondary schools. *Frontiers of Education in China, 2*, 366-377.

Yang, K.-L., & Lin, F.-L. (2012). Effects of Reading-Oriented Tasks on Students' Reading Comprehension of Geometry Proof. *Mathematics Education Research Journal, 24*, 215-238.

Zakaria, E., & Ngah, N. (2011). A preliminary analysis of students' problem-posing ability and its relationship to attitudes towards problem solving. *Research Journal of applied sciences, engineering and technology, 3*(9), 866-870.

Appendix A: IRB Documents

Appendix A1: IRB Approval

SMU.

Human Subjects Research Submission Approval Letter

Date: 8/20/2020
From: IRB Committee
To: Candace Walkington

The IRB Committee, or a designee thereof, completed review of your below-referenced submission and granted approval.   You are therefore authorized to begin or continue the research immediately.

Study ID:	H20-124-WALC
Study Title:	Investigating the Impact of the walkSTEM Program on High School Students' Mathematical Learning
Level of Review:	Expedited
Date of Submission:	8/10/2020
Type of Submission:	New Protocol
Approval Date:	8/20/2020
Continuing Review Due:	N/A

Please be advised of the following:

1. If a Continuing Review Date is shown above, a Continuing Review Report must be submitted to the IRB prior to that date in order to continue the research.

2. Any proposed changes to the protocol must be submitted to the IRB via an Amendment Form prior to implementation. Approval of an amendment does NOT change Continuing Review due dates.

3. Unanticipated Problems and Adverse Events must be reported to the IRB via an Unanticipated Problem / Adverse Event Form within 24 hours of the occurrence or upon acknowledgement of the occurrence.

4. All investigators and key personnel identified in the protocol must have documented Human Subjects Research training on file with this office. Certificates are valid for 3 years from completion date.

5. This study may be selected for a random audit under the Research Compliance Audit Program. These compliance audits maintain a comprehensive compliance program for the SMU research community and provide assurance that research is being conducted ethically, safely, and in accordance with an approved protocol.

Thank you,

IRB Committee

Office of Research and Graduate Studies
ResearchCompliance@smu.edu
214-768-2033 | smu.edu/research

Appendix A2: Follow up IRB Approval

SMU.

Human Subjects Research Submission Approval Letter

Date: 10/1/2020

From: IRB Committee

To: Candace Walkington

The IRB Committee, or a designee thereof, completed review of your below-referenced submission and granted approval. You are therefore authorized to begin or continue the research immediately.

Study ID:	H20-124-WALC
Study Title:	Investigating the Impact of the walkSTEM Program on High School Students' Mathematical Learning
Level of Review:	Expedited
Date of Submission:	9/15/2020
Type of Submission:	Amendment
Approval Date:	9/30/2020
Continuing Review Due:	N/A

Please be advised of the following:

1. If a Continuing Review Date is shown above, a Continuing Review Report must be submitted to theIRB prior to that date in order to continue the research.

2. Any proposed changes to the protocol must be submitted to the IRB via an Amendment Form prior to implementation. Approval of an amendment does NOT change Continuing Review due dates.

3. Unanticipated Problems and Adverse Events must be reported to the IRB via an UnanticipatedProblem / Adverse Event Form within 24 hours of the occurrence or upon acknowledgement of the occurrence.

4. All investigators and key personnel identified in the protocol must have documented Human Subjects Research training on file with this office. Certificates are valid for 3 years from completion date.

5. This study may be selected for a random audit under the Research Compliance Audit Program. These compliance audits maintain a comprehensive compliance program for the SMU research community and provide assurance that research is being conducted ethically, safely, and in accordance with an approved protocol.

Thank you,

IRB Committee

Office of Research and Graduate Studies
ResearchCompliance@smu.edu
214-768-2033 | smu.edu/research

Appendix B1 PRISMA Flow Diagram
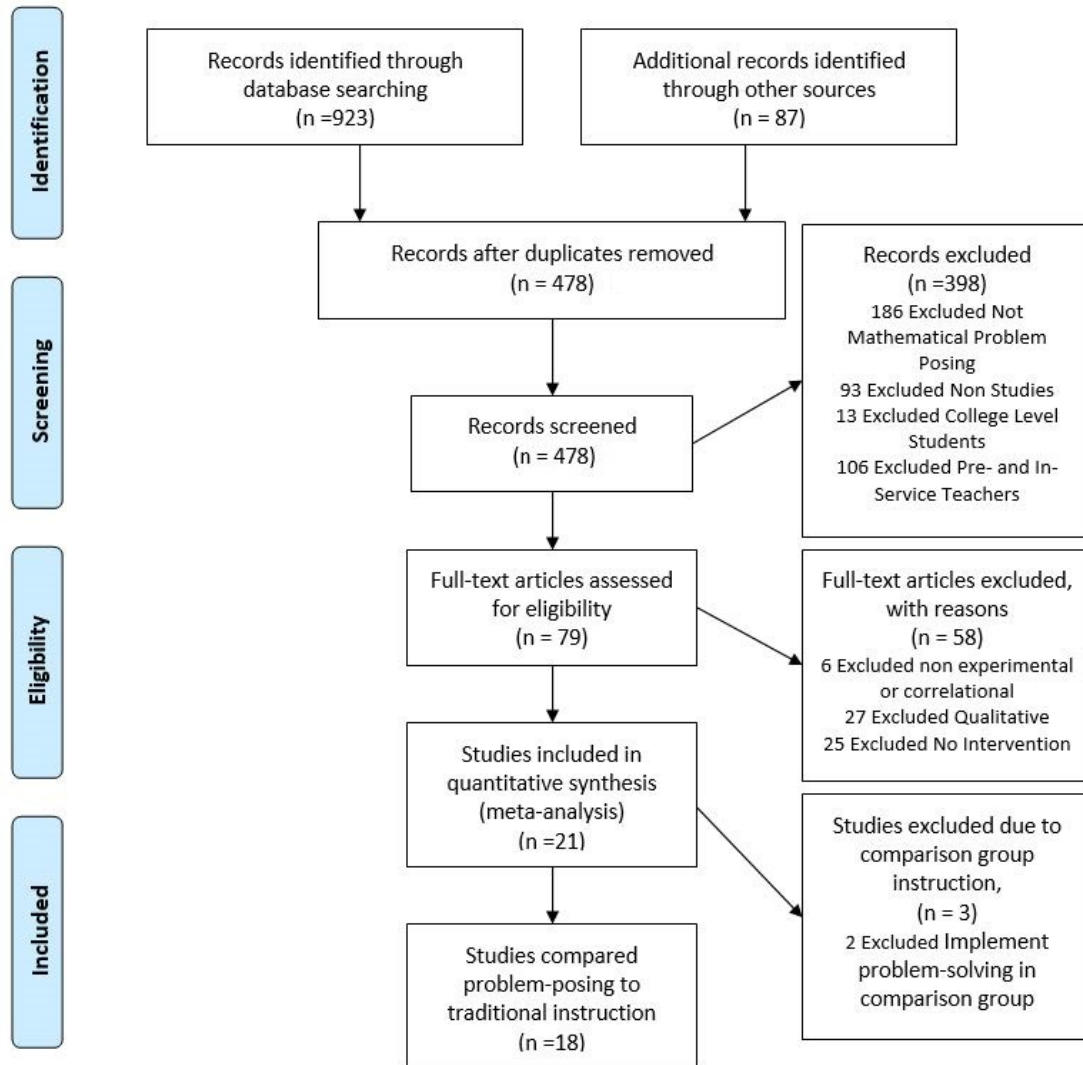
Appendix B2 Summary Table of the Selected Quantitative Studies

Study	Grade	N	Publication Type	Problem-Posing Tasks in Treatment Groups	Instructional Context	Learning Outcome (Effect Size)
Cotic & Zuljan, 2009	3	179	Journal	Students in the treatment group received problem-based instruction including students formulating and solving problems deriving from student's real experiences.	Third-Grade Math	Achievement (.12; .43) Problem-Solving (.48)
Demir, 2005	10	82	Dissertation/thesis	Students received 30 hours of instruction during 6 weeks. For each session, students were first lectured for 10-20 minutes about the context, and then would be doing these following tasks in order: reformulate given problems, change elements to formulate new problems (what-if-not), pose problems with insufficient information, pose problems with different contexts but same solutions, pose problems with same context but different solutions, and free problem-posing.	Probability	Achievement (.89) Dispositions (1.01; .91)
English, 1997	5	27	Journal	Ten-week PP program (two 35-minute sessions per week): wk 1 problem perceptions and preferences; wk 2 recognition of problem structures; wks 3-5 problem structure analysis and modelling new problems; wks 6-8 PP from giving problem components; wks 9-10 transform problems into new problems.	Operational Problems	Problem-Posing (.18)
English, 1998	3	53	Journal	Sixteen 45-minute sessions: session 1-5 PP and PS with hands-on materials; session 6-9 patterning activities and PP with hands-on materials and activity cards; session 10 PP from non-goal specific situations; session 11-12a PP for standard addition and subtraction number sentences; session 12b-13 PP from a picture; session 14 PP from	Operational Problems	Problem-Posing (1.95)

				literature; session 15-16 planning a class stall using PP and PS.		
Fidan, 2008	5	48	Dissertation/thesis	Ten-week PP program (two-hour lesson per week). Teachers implemented PP in their instructions with sample PP activities provided by the researcher: PP about real-life scenarios, posing problems with multiple answers, and solve the generated problems.	Fifth-Grade Math	Problem-Solving (.69)
Guvercin & Verbovskiy, 2014	8	54	Journal	Seven-week program (4 lessons per week, 8 hours in total). Teachers utilized the PP activity sheets prepared using PP word problem statements.	Eighth-Grade Math (word problems)	Achievement (1.67) Dispositions (1.02)
Katranci, 2014	7	68	Dissertation/thesis	Six-week PP program in collaborative learning environment (24 hours in total) including a short lecture on PP, 5 semi-structured PP, 4 structured PP, 5 free PP, and 12 PP homework assignments.	Seventh-Grade Math (statistics, probability, word problems, Algebra)	Achievement (.56; .67; .48)
Kurt, 2015	6	64	Dissertation/thesis	Four-week PP program (5 hours per week) including a lecture on semi-structured and free PP tasks and PP activities (e.g., PP from a set statement, reformulate a given problem, PP based on diagram, PP with given answers, exchange problems with peers to solve, provide feedback to peers).	Number Sets	Achievement (1.76) Achievement -8wks (1.13) Dispositions (.52)
Mayan, 2019	7	100	Dissertation/thesis	Five-week PP program (2 hours per week) following the five-stage PP program in English (1997): problem perceptions and preferences, recognition of problem structures, problem structure analysis and modelling new problems, PP from giving problem components, transform problems into new problems.	Mathematics Literacy (statistics, word problems)	Achievement (.73)

Ozdemir & Sahal, 2018	6	69	Journal	Five weeks of instruction following the PP approach: pose problems similar to example problems, PP based on a story or a piece of information, solve self-generated problems.	Sixth-Grade Math (sorting integers, 4 operations, number line)	Achievement (.52) Dispositions (.29)
Priest, 2009	7	31	Dissertation/thesis	Seven 1-hour sessions PP teaching experiment (1 hour per week): wk 1 consider problems with multiple solutions and do PP by modifying given problems; wk 2 learn criteria of "good" problems, do PP and provide peer feedback; wk 3 pose more complex problems based on a photo; wk 4 learn about quality solutions and do PP with geometric shapes; wk 5 rate problems against the "goold" problem criteria and do PP about a skateboard and an ipad; wk 6 solve 3D problems and do PP with visual aids; wk 7 showcase and share the visually-posed problems.	Seventh-Grade Math	Mathematics achievement
Salman, 2012	6	95	Dissertation/thesis	Ten-week program including PP and PS: 2 weeks of PS training and activities (6 hours); 4 weeks of PP activities (e.g., PP with problem statements, number sentences, and modifying given problems, PP with given real-life scenarios; and do free PP, exchange to solve problems and provide peer feedback),	Sixth-Grade Math	Problem-Solving (.65) Dispositions (.73; .69; .56; .61)
Suarsana et al., 2019	11	119	Journal	Online and paper-based PP. Students first solved problems and then modified the problems based on directions given by the teacher using lottery (e.g., change data or information, add data or information, change the value of the data, and change the problem context). Students then solved the new problems in groups, presented	Eleventh-Grade Math	Problem-Solving (1.30; .71)

				problems, uploaded problems to online system, and received feedback from the teacher.		
Turhan, 2011	6	40	Dissertation/thesis	Six-week PP program (27 hours in total). PP activities were embedded in decimal fraction instructions. PP tasks including free, semi-structured, and structured PP (e.g., PP based on given problems, PP from number sentences).	Sixth-Grade Math (decimal, fractions)	Problem-Solving (.40) Problem -Posing (1.18)
Authors, date	8	171	Conference proceeding	In this study, students in groups were asked to pose algebra problems relating to linear functions (y=mx+b) relating to an interest area (e.g., video games) that they shared with group members. They were given information on what the parameters of the linear function should look like (e.g., negative slope) and examples of personalized problems for that equation type to work from.	Early Algebra, Algebra, and Number Concepts	Achievement (.10) Dispositions (-.03; .06)
Yalçin,2007	5	52	Dissertation/thesis	Six-week program (1 session per week). PP activities related to the content were embedded in each session. Students were asked to solve and discussed the problems in groups first and were then given PP worksheets to pose and present problems. Worksheets included free, semi-structured, and structured PP.	Fifth-Grade Math (operations, natural numbers, decimal, measurement)	Problem-Posing (.70)
Yang & Lin, 2012	9	633	Journal	Two 45-minute lessons on reading comprehension of geometry proof. Two types of during problem-solving PP tasks: statement-posing tasks (SP) and reading mathematics proofs tasks (RP). The RP task asked what could be inferred based on the given from the geometry proof problem and the SP task asked what could be proved based on the given arguments.	Geometry Proof	Achievement (.12; .19)

Guzel, 2017	8	39	Dissertation/thesis	Two-week PP program (4 hours per week) included free, semi-structured, and structured PP tasks such as PP based on given solutions, inequality statements, solution characteristics (e.g, solution with negative coefficients).	Eighth-Grade Math (algebra)	Achievement (.10) Achievement -3wks (.01)
Kapur, 2015-Study 1*	9	72	Journal	Two 1-hour phases. Phase 1: students were presented with a statistics problem about football strikes. Students were asked to generate as many problems as possible based on this football strikes scenario individually. Students were asked to solve the posed problems. Phase 2: Students received the instruction on standard deviation together.	Statistics (standard deviation)	Achievement (-.12; -.05; -.31) Dispositions (.12; .06) Problem-Solving (.66)
Kapur, 2015-Study 2*	9	71	Journal	Two 1-hour phases. Phase 1: students were presented with a statistics problem about football strikes. Students were asked to generate as many problems as possible based on this football strikes scenario individually. Students didn't have to solve the posed problems. Phase 2: students received the instruction on standard deviation together.	Statistics	Achievement (-.2; .02; -.82) Dispositions (.14; -.04) Problem-Solving (.48)
Dickerson, 1998*	7	118	Dissertation/thesis	Two-year study. The 1st year took place over 20 weeks with 4 PP activities ("structured", "acting-out", "open-ended", and "what-if-not"). The 2nd year involved students receiving either "structured" or "what-if-not" PP and took place over ten weeks. Structured PP: students pose problems that could be solved by a certain strategy. Acting-out PP: students use props to act out real-life scenarios and pose problems accordingly. Open-ended PP: students pose problems from a story starter.	Seventh-Grade Math (PS)	Achievement (.91; .64; .84)

| Kopparla et al., 2019* | 3-5 | 45 | Journal | Three-month program (two 15-20 min session per week). Students were provided with real-world pictures, objects or manipulatives to pose problems. Students evaluated the posed problems to determine if problems are solvable, realistic, and formulated appropriately. | Early Elementary PS | Problem-Posing (-.08) Problem-Solving (-.08) |

Note.

There are two separate studies reported in Kapur (2015).

CBD = cannot be determined; PP = problem-posing; PS = problem-solving.

*the studies were only included in the meta-analysis that compared problem-posing to problem solving.

The label for problem-posing task structure: 1- free problem-posing; 2- semi-structured problem-posing; 3- structured problem-posing.

Appendix C: Measurement Instruments and Codebook in the Pilot Study

Appendix C1: Pilot Study Pre- and Post-Survey

Pre- and Post-:

Please consider your experience with the walkSTEM club.					
2.1 Triggered Situational Interest	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) The walkSTEM club is exciting.					
2) The walkSTEM club grabs my attention.					
3) I find the walkSTEM club entertaining.					
4) The walkSTEM club meetings seem to drag on forever.					
2.2 Maintained Situational Interest - ENJOYMENT					
1) The topics in the walkSTEM club are fascinating to me.					
2) I am excited about what I learn in the walkSTEM club.					
3) In the walkSTEM club, I really enjoy the math.					
4) To be honest, I don't find the walkSTEM club interesting.					
2.3 Maintained Situational Interest - VALUE	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) The math I learn in the walkSTEM club is useful for me to know.					
2) The topics I learn in the walkSTEM club are important to me.					
3) The math I am learning in the walkSTEM club is important for my future goals.					
4) What I am learning in the walkSTEM club can be applied to real life.					
Please consider your feelings about math.					

3.1 Individual Interest (math) (Linnebrink-Garcia et al., 2010)	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) Math is practical for me to know.					
2) Math helps me in my daily life outside of school.					
3) It is important for me to be a person who reasons mathematically.					
4) Thinking mathematically is an important part of who I am.					
5) I enjoy the subject of math.					
6) I like math.					
7) I enjoy doing math.					
8) Math is exciting to me.					

3.2 Maintained Situational Interest - ENJOYMENT (math)	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) What we are learning in math class this year is fascinating to me.					
2) I am excited about what we are learning in math class this year.					
3) I really enjoy the math we do in this class.					
4) To be honest, I don't find the math we do in class to be interesting.					

3.3 Maintained Situational Interest - VALUE (math)	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) What we are studying in math class is useful for me to know.					
2) The things we study in math this year are important to me.					
3) What we are learning in math this year is important for my future goals.					
4) What we are learning in math class can be applied to real life.					

3.4 Mastery Approach Goals	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree

1) My aim is to completely master the material presented in math class.					
2) My goal is to learn as much as possible in math class.					
3) I am striving to understand the content in math class as thoroughly as possible.					
3.5 Performance Approach Goals	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) I am striving to do well in math class compared to other students.					
2) My aim is to perform well relative to other students in math class.					
3) My goal is to perform better than other students in math class.					
3.6 Performance Approach Goals	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) My goal is to avoid performing poorly in math class compared to others.					
2) I am striving to avoid performing poorly in math class compared to others.					
3) My aim is to avoid doing worse than other students in math class.					
3.7 Self-Efficacy	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) I am confident that I will do well in math class.					
2) I expect to do well in math class.					
3) I am confident that I can learn future math concepts in math class.					
4) Considering the difficulty of my math class, I think I will do					

well in mathematics in the future.					
5) I am confident that I will do an excellent job on future math problems in math class.					

Pre-Survey only:

1. Which grade level are you in?

   _____

2. What's your favorite subject in school?

   _____

3. What are some of your interests or hobbies?

   _____

4. Why did you decide to join the walkSTEM afterschool club?

   _____

5. Do you have any experience creating your own math problems?

   A. Yes, I have created math problems before.

   B. I have only created problems in other subjects, not math.

   C. No, I don't have experience in creating problems.

Post-survey only:

1. What was your favorite part about the walkSTEM afterschool club?

2. What was your least favorite part about the walkSTEM afterschool club?

3. Which meeting did you like most during this program?

   _____

4. How did you like making your own walkSTEM stops?

5. How did you like leading your own walkSTEM walk?

6. Do you think creating your own problems in this program is difficult?

    A. Very difficult for me.

    B. It was difficult at first but it got easier afterward.

    C. I met some problems but I was able to solve it.

    D. It is easy for me to create problems.

7. What suggestions do you have for this program?

_____

Appendix C2: Pilot Study Student Interview Protocol

I appreciate you letting me interview you for the research. I have some questions for you about

the walkSTEM afterschool club that you attended. I will record this interview and the interview

will only be used for this research.

- **Part 1: Background Information**
  - o Which grade level are you in?
  - o What's your favorite subject in school?
  - o What are some of your interests or hobbies?
  - o Why did you choose to attend this afterschool program?
- **Part 2: Disposition Toward Problem Posing**
  - o Do you have any experience of creating problems before attending this program?
  - o How do you like the process that you create your own problems in this program?
  - o What are some of the challenges that you encountered when creating your own problems?
  - o Can you describe one specific example that you created a problem that you really like in this program?
  - o Does your disposition or understanding toward mathematics change because of this program?
  - o If so, can you describe some of the differences?
  - o What suggestions do you have for this program if we are going to run this next semester?
- **Part 3: Wrap Up**
  - o Finally, is there anything else you want to share with me about your experience with this afterschool program?

Thank you so much for attending this interview! Your opinion is really important for our study

Appendix C3: Pilot Study Teacher Interview Protocol

I appreciate you letting me interview you for the research. I have some questions for you about

the walkSTEM afterschool club that you've been running. I will record this interview and the

interview will only be used for this research.

- **Part 1: Teaching Background**
  - How long have you been teaching at this school?
  - Which grade levels and subjects do you teach?
  - How long have you been teaching/ leading this afterschool program?
- **Part 2: Afterschool Program Planning**
  - What resources did you use to plan for this afterschool program?
  - Could you please tell me about a time you use the resources for planning (a concrete example)?
  - Did you receive any support from other teachers or the school? If so, can you describe the support to me?
- **Part 3: Student Behavior**
  - What benefits do you think this program has on your students?
  - What do you think of students' problem posing performance in this program?
  - Did you recognize any differences in students' behaviors during this program?
- **Part 4: Classroom Instruction**
  - What was your disposition or understanding toward students' problem posing before teaching in this program?
  - How do you think your disposition has changed now?
  - Does this shift in disposition influence your classroom instructions? If yes, what are the differences?
  - Can you describe one lesson or one teaching activity that you think demonstrate the differences you mentioned?
- **Part 5: Wrap up**
  - Is there anything else you want to share with me regarding your experience leading this afterschool program?

Thank you again for participating in this interview!

Appendix C4: Pilot Study Video Analysis Codebook

Categories	Codes
Students' Problem-Posing Procedures	Students observe their surroundings; Students pose questions; Students select the question to solve;
Students' Problem-Posing Behavior	Students make connections with real-world scenarios; Students pose problems about various topics; Students collaborate with peers to pose problems; Students introduce problem-posing to others; Students explain what is problem-posing; Students evaluate self-generated problems.
Students' Problem-Solving Procedures	Students problem-solving strategies; Students transfer prior problem-solving experience to novel problems.
Students Design and Create Final Walk	Students choose how to present the Final Walk; Students' dispositions toward video making.
Students Lead the Final Walk	Students alternate to think from a problem-solver vs poser perspective; Students' participation in the Final Walk.

Appendix D: Instructional Materials

Appendix D1: Video-Watching Questionnaire

Q1. What object/place is this walkSTEM video based on? *

○ Built environment (building, statue, etc)

○ Natural environment (trees, plants, etc)

○ Artwork

○ Everyday object

○ Other:

Since you selected yes.

Please briefly explain why you think this video is related to math. *

Your answer

Since you selected no.

Please briefly explain why you think this video is not related to math. *

Your answer

Q4 What did you learn from this video? (select all that apply) *

☐ something that connected to a topic I learned about at school

☐ something completely new that I've never thought about

☐ a new way to connect a math topic to real-world scenarios

☐ a new way to connect a science topic to real-world scenarios

☐ a new way to connect a computer science, engineering, or fine arts-related idea

☐ Other:

Q5. Imagine you want to use the same video content (the same object or location that you just saw), but you want to focus on a different math, science, STEM, or STEAM question. What questions would you focus on, based on what you can see? List 1-3 questions. *

Your answer

Q6. What do you like about this video? (select all that apply) *

☐ This video makes me think about math, science, STEM, or STEAM in a new way.

☐ I enjoyed seeing the connection between real-world objects or locations and math, science, STEM, or STEAM.

☐ This video inspired me to think of other questions.

☐ This video was just the right length.

☐ Other:

Appendix D2: Lesson Plans for Online Meetings in the walkSTEM Program

<u>Oct 17 Lesson Plan</u>

Whole Group Session
1. **Go to the Zoom meetings and start recording:**
   a. Go to the Zoom meeting using this link: <LINK>
2. **Introduction by tutor (5min):**
   What is the walkSTEM Program and the walkSTEM Game?
   We are going to have some fun over the next 6 weeks. We will all participate in the walkSTEM program and the walkSTEM game. The main goal is for you to make connections between your real world places and math and science concepts you've learned in your classes at school. You will have a lot of choice on what places you will focus on and what topics you want to think more about. You will be taking a lot of photos and In early December you will take us on a tour of the places you have chosen.

   Possible Discussion questions:
   1. Why do you think it's a good idea to make connections between what you're learning at school and your own places that you live in and move around in?
   2. Who likes taking photographs?

   This program is extra special because a graduate student is focusing on learning what she can about how this type of activity helps students think about what they learn at school and beyond. So Min Wang, who is working on her PhD in math education here at SMU wants to observe how we work. …
3. **Paperwork (30min)**
   a. Guide students to go to the Pre-Survey link on Canvas. <Link>
   b. Students should complete the pre-survey individually.
   c. Extend some time if some students can't finish in 30 mins.
4. **Intro to Gameboard (10-12min)**
   For the next few weeks, we are all going to focus on playing the walkSTEM game. There are 2 main activities in this game:
   - Taking virtual field trips through some short videos
   - Taking photos of your real world spaces at home, in your neighborhoods, etc
   You're going to be gaining points as you do these activities on your own gameboard. So the next thing we need to do is for each of you to **claim your gameboard (the gameboard tutorial is on Canvas).**
   a. Guide students to each claim their own gameboards (the gameboard folder can be accessed here: <Link>
   b. Spend 8-10 mins walking through the gameboard and get them familiar with the first few tabs that relate to the videos and the #STEMlens.
   c. Tell them not to worry about the walkSTEM project tab right now.

Breakout Sessions

1. <u>**Record the breakout room on Zoom.**</u>
2. **How will you earn points on your gameboard?** (use strategies to make this fun and a friendly competition) – 12-14min
   - The main way is by taking photos and taking virtual field trips. Let's practice!
     a. Show your sample #STEM lens photos
     b. Show the rubric and discuss how they'd evaluate 1 or 2 of the photos that are posted
     c. Now each person needs to take a photo (#STEMlens photo) – does not matter what it is. Practice marking up the photo, adding their STEM observation or question, and uploading.
     d. Make sure all students can do this.
     e. If some students need more time, have the ones who are done practice self-evaluating using the #STEMlens rubric.
     f. Have students go to their gameboards and put in their first #STEMlens and put in 10 points in the first orange "points earned" cell on the "My #STEMlens" tab.

3. **Let's take a field trip to SMU! – 20mins**
   a. Watch each of the 2 videos; make sure students complete and submit video-watching forms (they have to complete one form for each video watched).
   b. Let them know they will be receiving points on their gameboards for these forms.
   c. Guide students to mark completion for the watched videos on the gamboards to earn points.

4. **Wrapup:**
   How can you score more points on your gameboard between now and our next meeting on _____?
   (1. watching the bonus videos – highlight that they should only watch the videos listed under the bonus videos tab and not the others!
   And 2. taking as many #STEMlens photos as they are inspired – take a minimum of 3. We will have a chance to look at each others' photos and discuss so it'll be really fun for us to see what you see. I plan on taking some photos of ___ (*tutor should role model by thinking aloud*).)

Week of Oct 26th to 30th – 30 min check-in

1. Go to the Zoom meetings and start recording:
   a. Go to the Zoom meeting.
   b. **Record the meetings locally if there is enough space on your laptop/PC.**
      (if not, record to cloud instead)
2. Virtual field trip (walkSTEM videos)
   a. Watch the three videos in Canvas Module "Oct 26th to 30th"
   b. Complete three video-watching forms (one for each video watched)
   c. Make sure students have "submitted" their responses
   d. You can always check if their responses have been saved from Canvas:
   Home-> Lesson Plans, Zoom Links, and Video Recordings-> Video-Watching
Questionnaire Responses
   e. Gain points on the gameboard
3. Check-in for #STEMlens photos
   a. Students should each submit at least 3 #STEMlens pictures to Canvas this week
   b. Guide students to pose their #STEMlens pictures to Canvas discussion boards
      i. students should only submit one #STEMlens picture to one discussion
         board
      ii. when submitting multiple pictures, make sure to use multiple discussion
          boards to submit (e.g., #STEMlens submission 1, #STEMlens submission 2,
          …)
   c. Discuss self-evaluation and peer-feedback using the rubric
      i. Go to the #STEMlens rubrics from the walkSTEM Gameboard, tab
         "Rubrics"
      ii. Guide students to do self-evaluation using the rubric (e.g., what do you
          think your picture should get according to the rubric?)
      iii. Encourage students to give peer-feedback to their group members using
           the discussion board (e.g., hit reply on the discussion board to provide
           feedbacks to other students' posts; use the "like" button to indicate what
           are the three #STEMlens pictures they like the most on the discussion
           board; discuss why some #STEMlens pictures receive more likes than
           others?)
      iv. Guide students to go to the walkSTEM Gameboard to gain points for the
          #STEMlens submissions.
4. Wrapup:
   a. Remind students ways to gain points and win pokemons on their gameboards
      between now and our next meeting on _____?
      i. watching the bonus videos – highlight that they should only watch the
         videos listed under the bonus videos tab and not the others!
      ii. 2. taking as many #STEMlens photos as they are inspired – take a
          minimum of 3. We will have a chance to look at each others' photos and
          discuss so it'll be really fun for us to see what you see. I plan on taking
          some photos of ___ (*tutor should role model by thinking aloud).)*

Lesson Plan for the Week of Nov. 2nd

1. Go to the Zoom meetings and start recording:
   a. Go to the Zoom meeting.
   b. **Record the meetings locally if there is enough space on your laptop/PC. (if not, record to cloud instead)**
2. Check in with students on the #STEMlens pictures
   a. #STEMlens whole group discussion using the photos that students and tutors submitted
      (tutors, please submit at least one new #STEMlens photo before Nov. 2nd to #STEMlens Submission 1 discussion board).
      i. Look through the photos on #STEMlens Submission 1 discussion board and some sample #STEMlens photos in the google drive:
         <Link>
      ii. Talk about which photos/questions you like the most and why.
      iii. Try to think of other questions you can ask about this photo.
   b. Guide students to submit one #STEMlens photo **during the meeting** (each students should have at least one #STEMlens photo submitted by Nov 7th).
      i. Talk about the walkSTEM project that we'll start to work on from Nov 7th. The #STEMlens photos are the building blocks of the walkSTEM project. We'll use the photos we take to create a STEM walk. We can make a video out of the walk and upload it to Youtube.
      ii. Let's each take a #STEMlens photo now and submit to Canvas together. Direct students to #STEMlens submission (week of Nov. 2nd) to submit their #STEMlens so that they can see each others' photos all at one place.
      iii. Talk about self-evaluation of the #STEMlens.
         1. Use the rubric to do self-evaluation (e.g., how many points do you think you should get for this #STEMlens photo according to this rubric).

How tall are the two rabbits ?

         2. Do a modeling for students using your own #STEMlens photo (e.g., this is my photo of my rabbits. My initial question was how tall are my rabbits and I think it's not really interesting. I can perhaps ask what's the difference between the height measurements when a rabbit stands up and when a rabbit does the bunny loaf position and why is there such a big difference?)
         3. Guide students to check out their #STEMlens photos and encourage them to come up with more questions with deeper thinking (e.g., how can you make this question more interesting and fun for others? what else do you wonder about this object/place? It's totally fine if we do not know the answer for your questions now since we're focusing on the questions now).
3. Virtual field trip (walkSTEM videos)
   a. Use the rest of the time to watch the walkSTEM videos under Nov 2nd to 6th module on Canvas.

b. Paste the links of the videos in Chat on Zoom so students can watch the videos from their own laptop/computer.
c. Complete three video-watching forms (one for each video watched)
d. Make sure students have "submitted" their responses
    i. You can always check if their responses have been saved from Canvas: Home-> Lesson Plans, Zoom Links, and Video Recordings-> Video-Watching Questionnaire Responses
    ii. Gain points on the gameboard
e. There are 4 walkSTEM videos in the module. It's okay if students don't finish watching all of them. Encourage students to finish the unwatched videos after class.

<u>Nov 7 Lesson Plan</u>

Today is an important day - project kickoff day. Please make sure you spend **at least 90mins** of your session time on the project (step 3 onward in the lesson plan)

Reminder for tutors about the walkSTEM Project:

The goal of this project is very simple - get your students to make connections to their real world spaces (home, neighborhood, campus etc) and to math/science topics. Tell your students that they will be taking us all on a math/science/STEM-integrated guided tour and their project is to plan this all out. We want to see what they see.

The basic criteria are:

a. photos of their real world places (they can have a minimum of 1 photo per stop but we suggest encouraging them to add more photos from different angles, closeups, or whatever it takes for them to share what they see with the rest of us)

b. their authentic questions (and if you think they are too textbook-y or same-y, tell them that and get them to think again) - 1 per stop.

c. responses to each of their authentic questions

A **walkSTEM stop** is just like a **#STEMlens photo** except now, students need also to respond to the question they raised.

NOTE: Each tutor has **creative license** while guiding your students. Encourage and guide in whatever ways are appropriate to get your students to be successful. We want them all feeling great when they present in December! Get them to think about this as a performance-presentation hybrid. They can use props, they can rehearse ahead of time - there should be some great energy! They will be using powerpoint during their presentations on STEM Day on Dec 5.

By the end of today's walkSTEM session, each student should:
- Complete walkSTEM project planning sheet
- Complete 2 walkSTEM stop design worksheets
    (photos to be used can be taken during the session if there's time and if students' selected stops are at home - which will not necessarily be the case and which is totally fine)
- Watch 3 videos that make up a student-created walkSTEM tour
    <u>Note:</u> the 2 videos listed in the gameboard can be viewed by students for bonus points. We are using class time for the project itself instead.

Lesson Plan Details:
1. Go to the Zoom meetings and start recording:
    a. Go to the Zoom meeting.
    b. **<u>Record the meetings locally if there is enough space on your laptop/PC.</u>**
        <u>(if not, record to cloud instead)</u>

2. Warm-Up Activity (5 min)
    a. What pokemons have you caught in the Gameboard?

b. Let's share what pokemons have you set up for level 10 (students can set up what pokemon they want to win for level 10 on the "My Pokemons!" sheet)!

3. **Virtual field trip - walkSTEM tour at Mt Auburn STEAM Academy in DISD** (15 min):

Tell students: We are going to be kicking off your walkSTEM projects today. You will be working on your own but will also be part of a team.

Let's first watch some young people who did a similar project (they had a little longer time so they made videos) where they designed a walkSTEM tour on their school campus. Even though these are videos, you will be doing the same basic steps of selecting a real world space/object, coming up with a question, and then responding to your question at each walkSTEM stop.

Note: Have students watch all 3 videos consecutively - tell them to make a note of anything interesting as they watch so you can all discuss after everyone has watched the 3 short videos. You will be asking what each of them made a note of.

a. Watch these 3 videos (total viewing time is 5 mins): the swing stop video; the geodome stop video, and the big number stop video.

b. Discuss: Ask students what they thought of the key question at each stop. Ask them for alternative questions that they would have asked at a couple of these stops (given that they are in high school).

4. **Intro to walkSTEM project (5 min)**
   a. All information related to the walkSTEM project is listed on the "walkSTEM Project Outline and Planning Sheet". ***Please make sure you are completely comfortable with all aspects of this project before this session.***
   b. **Tell students:** You will be taking us all on a math/science/STEM-integrated tour! Your project is to plan this all out, include all visuals and make it fun and exciting for us. We want to see what you see! You already have been working on pieces of this project so now it's a question of putting the pieces together.

      The basic building blocks of this project are:
   - photos of your real world places (you can have a minimum of 1 photo per stop but you may want more). These are your #STEMlens photos - you can choose something you've already taken or you can take new photos - does not matter.
   - Your questions - 1 per stop
   - Your responses to each of your questions

   Ask: How is a walkSTEM stop different from a #STEMlens photo?

   A **walkSTEM stop** is just like a **#STEMlens photo** except now, students need also to respond to the question they raised.

5. Go through the **"walkSTEM Project Planning Sheet" for each student. In the folder, you can find the planning sheet with your students' names on it (if there is no planning sheet of yours, rename a "copy of walkSTEMProjectOutline+planning+sheet" to be your name).**
   a. Go through page 1 of the planning sheet together with the students.

b. Go through the top of p2 together and decide which theme your group would like to do - tell them that when they present on Dec 5, each person will present a couple of their stops to everyone. Having a theme will make this all work better. Here is the top part of p2 - we've added a few clarifying notes:

_____ 1 or more AP STEM or other STEM courses you are currently taking *(these can be the same or different STEM courses - does not matter)*

_____ A STEM topic or concept that you are currently or have recently learned about *(examples are: mathematical relationships or functions, forces, geometry, ecology, plants).*

___ A Place (e.g. your neighborhood, a park, your home, school campus, etc.)

_____ An Activity (e.g. a sport or hobby that requires participating in the physical, 3D world. Hobbies that involve screen-based interactions only are not permitted for this project)

c. After the top part of p2 is completed, each student then **individually** completes the bottom part of p2. If one student wants to use videos but not the others, that's fine.
d. Walk through the project rubric on p3 of the packet so that everyone is familiar.

6. Create the first stop! (20 min)
   a. **Go to the "walkSTEM Project Design Worksheet" folder and find the design worksheet with your students' names on it (if there is no planning sheet of yours, rename a "copy of Design Worksheet: Design a walkSTEM Stop" to be your name).**
   b. Each student completes one design worksheet for a single stop that they are planning. They can type into the worksheet which is a google sheet.
      Tell: The goal today is to :
      - think of all 3 stops and tell you what they are
      - Complete design worksheets 1 and 2 for their stops (2 stops at minimum, more if there is time - students can work ahead if done with 2; there is an optional 4th stop)
      - Tell you if they already have photos for these stops or if they need to go and take the photos for these stops.
      - For students whose stops involve taking photos that are not at home, tell students they need to tell you what their plan is as to when they will be taking those photos and uploading photos on their design worksheets. **Please make a note of each of your students' plans and during the check-in session (week of Nov 9) make sure to follow up.**
   c. As they are working on worksheet #1, each student will share their photos/ ideas for photos, provide feedback to each other, and use the rest of the time to complete the design worksheet. Repeat for worksheet #2

7. Plug for #STEMlens photo submissions and for attending the short check-ins during the week: Some of you have been sharing some really cool pictures - please continue doing

this and we will talk about them in the next few weeks too. The more photos the better! Hope to see you all next week and we can look at your submissions - and you'll be gaining points as well, of course!

      Note: for groups that have a little time, you can have a quick discussion on uploaded photos on discussion board at end of today's session. If no time, no worries.

8. Wrapup (5 min)
    a. Remind students ways to gain points and win pokemons on their gameboards between now and our next meeting in a few days on ____?
        i. Watching **Video 10 and 11 in the module "Nov 7th"** and the bonus videos.
        ii. taking as many #STEMlens photos as they are inspired. We will have a chance to look at each others' photos and discuss so it'll be really fun for us to see what you see. I plan on taking some photos of ____ (*tutor should role model by thinking aloud).)*

Nov 9th to 13th Lesson Plan

Note: if there are students in your group who didn't attend the Nov. 7th walkSTEM session, briefly talk about the walkSTEM project, the tour theme your group had decided to go with to the student(s). Let the student(s) know that the completion of the walkSTEM planning sheet is important and they should finish that this week. For this 30-min check-in session, all students (including those who were absent for the walkSTEM project launch day) should be working on finalizing their walkSTEM stop#1 and give peer-evaluation to each other.

To all tutors, please make sure to submit a new #STEMlens photo to the #STEMlens submission (week of Nov. 9th) on Canvas.

By the end of today's walkSTEM session, each student should:
- Finish the 2 walkSTEM stop design worksheets
- Finalize at least 1 walkSTEM stop (finalize the question and the response to the question with the help from the tutors)
- Watch 1 video and complete the video-watching form **if the students have finished the 2 walkSTEM stops**

Lesson Plan Details:
1. Go to the Zoom meetings and start recording:
   a. Go to the Zoom meeting.
   b. **Record the meetings locally if there is enough space on your laptop/PC. (if not, record to cloud instead)**

2. Warm-Up Activity (5 min)
   a. What pokemons have you caught on the Gameboard?
   b. Have you taken any new #STEMlens photos or watched any bonus walkSTEM videos this week?
   c. Give a shout out for students who posted new #STEMlens photos on the discussion board.
   d. Go to the discussion board to review the new #STEMlens photos submitted by students and tutors. What new #STEMlens photos do you want to take this week (tutors should role model for students by thinking aloud)?

3. #STEMlens photos/video for walkSTEM stop#1 (20 min)
   a. **Please use the note that you took on Nov. 7th about your students' plans of taking photos/videos and follow up with their plans.**
   b. Guide students to go to their **walkSTEM Project Planning Sheet** and **walkSTEM Project Design Worksheet**.
   c. Let's do a round of sharing first to remind us what our walkSTEM project theme is and what each one of your first stops on your walkSTEM tours are (encourage students to share their photos and questions with the group and get some peer feedback from the group members).
   d. What's your walkSTEM plan for this week?

   i. **Again, please make a note of each of your students' plans and during the next check-in session (week of Nov 16th) make sure to follow up.**

 e. Let's use the rest of the time to continue working on our walkSTEM project.

   i. For those who haven't started yet, do the planning sheet first.

   ii. For those who have already finished the design worksheets for stop#1 and #2, use this time to edit your photos/videos, polish your questions and your responses to the questions.

    (tutors should check in with each individual student to help them pose questions with deeper thinking and come up with a proper answer/strategy to their questions; encourage students to use online resources to find the answer/strategy)

4. **Virtual field trip - walkSTEM tour to Target** (it time permits):

  Note: The target walkSTEM video is on Canvas under the module Nov 9th to 13th Video 13.

 a. For students who have finished finalizing the walkSTEM design worksheets, let them know that they can start to watch the video and complete the video-watching form to gain points on the gameboard.

 b. Paste the link of the video in chat on Zoom: https://youtu.be/mFN1ACwhks8.

5. Wrapup (5 min)

 a. Remind students ways to gain points and win pokemons on their gameboards between now and our next meeting in a few days on ____?

   i. Watching **Video 12 in the module "Nov 9th to 13th"** and the bonus videos.

   ii. Taking as many #STEMlens photos as they are inspired. We will have a chance to look at each others' photos and discuss so it'll be really fun for us to see what you see.

Nov 16th to 20th Lesson Plan

Note: if there are students in your group who didn't attend the walkSTEM project launch session and the check-in session last week, briefly talk about the walkSTEM project, the tour theme your group had decided to go with to the student(s). Let the student(s) know that the completion of the walkSTEM planning sheet is important and they should finish that this week. For this 30-min check-in session, all students (including those who were absent for the walkSTEM project launch day) should be working on finalizing their walkSTEM stops and give peer-evaluation to each other.

Let students know that it's important for all of them to **at least have one walkSTEM stop ready (finish the design worksheet, and have the photo/video, questions, and responses ready)** before this Saturday. The group should be combining their stops to form a group walkSTEM tour this Saturday.

To all tutors, please make sure to submit a new #STEMlens photo to the #STEMlens submission (week of Nov. 16th) on Canvas.

By the end of today's walkSTEM session, each student should:
● Finish the walkSTEM stop#3 design worksheets and finalize the questions and the response to their questions with the help from the tutors.
    Note: for students who haven't finished walkSTEM stop#1 and #2, they should be working on stop#1 and stop#2's design worksheets.
● Watch 1 video and complete the video-watching form **if the students have finished all 3 walkSTEM stops before the end of the session.**

Lesson Plan Details:
1. Go to the Zoom meetings and start recording:
    a. Go to the Zoom meeting.
    b. **Record the meetings locally if there is enough space on your laptop/PC. (if not, record to cloud instead)**

2. Warm-Up Activity (5 min)
    a. What pokemons have you caught on the Gameboard?
    b. Have you taken any new #STEMlens photos or watched any bonus walkSTEM videos this week?
    c. Give a shout out for students who posted new #STEMlens photos on the discussion board.
    d. Go to the discussion board to review the new #STEMlens photos submitted by students and tutors. What new #STEMlens photos do you want to take this week (tutors should role model for students by thinking aloud)?

3. #STEMlens photos/video for walkSTEM stops (20 min)
    a. **Please use the note that you took on Nov. 7th and last week about your students' plans of taking photos/videos and follow up with their plans.**
    b. Guide students to go to their **walkSTEM Project Planning Sheet** and **walkSTEM Project Design Worksheet**.

    c. Let's do a round of sharing first to remind us what our walkSTEM project theme is and what each one of your first stops on your walkSTEM tours are (encourage students to share their photos and questions with the group and get some peer feedback from the group members).

    d. What's your walkSTEM plan for this week?

        i. **Again, please make a note of each of your students' plans and during the next walkSTEM session (Nov 21st) make sure to follow up.**

    e. Let's use the rest of the time to continue working on our walkSTEM project.

        i. Students who have already finished the photos/videos, questions, and responses for walkSTEM stop#1 and #2 should start to work on the walkSTEM stop#3 design worksheet.

        ii. Other students should at least finish the first two design worksheets fro stop#1 and stop#2 during this session,

            (tutors should check in with each individual student to help them pose questions with deeper thinking and come up with a proper answer/strategy to their questions; encourage students to use online resources to find the answer/strategy)

4. **walkSTEM video - video 14 How do you measure slope?** (if time permits):

    Note: The walkSTEM video is on Canvas under the module Nov 16th to 20th.

    a. For students who have finished finalizing the walkSTEM design worksheets, let them know that they can start to watch the video and complete the video-watching form to gain points on the gameboard.

5. Wrapup (5 min)

    a. Remind students ways to gain points and win pokemons on their gameboards between now and our next meeting in a few days on ___?

        i. Watching walkSTEM videos on the gameboard.

        ii. Taking as many #STEMlens photos as they are inspired. We will have a chance to look at each others' photos and discuss so it'll be really fun for us to see what you see.

Nov 21ˢᵗ Lesson Plan

THIS IS THE FINAL LONG MEETING DAY WE HAVE BEFORE YOU PRESENT ON DEC 5TH.

This session is a work session. The bulk of the time should be spent on completing the project and rehearsing. We suggest spending no more than 15 minutes on the initial check in (as described below). The goal is to ensure your students have maximum time available to get their work done and also for you to have maximum time to work individually with students who need your greatest attention. Have your students work at the steps they need to work at. Move between them to provide feedback. Have a whole group check-in half way through the session today to see where everybody is. Tell them in advance that you will be asking your group to come together at _____ (time) with the goal of making sure everybody is working productively and is on schedule.

Note: for tutors with students who are really behind, work with them to get their three #STEMlens photos ready. They don't have to complete the design worksheets in great detail - they can tell you what they're thinking and you can help them along. The goal is to get them to be able to present something that they can take pride in.

For tutors with students who are amazingly ahead, encourage them to plan for an exceptional presentation, and they can always gain more points on their gameboards. No student should be leaving early.

If anything comes up that you need some help on, do not waste time and please text me immediately. I'll show up in your zoom meeting. Here is my number: 315-706-1761 (Min Wang).

Ideally at the end of the session, each student should share a minimum of three photos with you that they plan on using for the presentation.

IMPORTANT: Each tutor will later import these images in a google slides deck. Make sure that you organize the sequence of the images in a way that makes sense so that when your students present it all flows well. Each tutor saves your slides deck to this folder: https://drive.google.com/drive/folders/1mSeWSjfs0tBQE_DHXdd-NXYdSpa7aMcb. Please make sure to save your slides deck under your name (tutor name). After this session, go ahead and save whatever your students have gotten ready even if they have not yet submitted three photos each.

Encourage your students to attend the final prep session during the week of Nov. 30th so that your group can have a really great presentation. For those students who have not submitted the photos they will be using for the Dec 5th presentation, please use the reminder app to encourage them to do so.

Recap with your students at the start of the session:
        Each of you made two choices about your walkSTEM tour design:
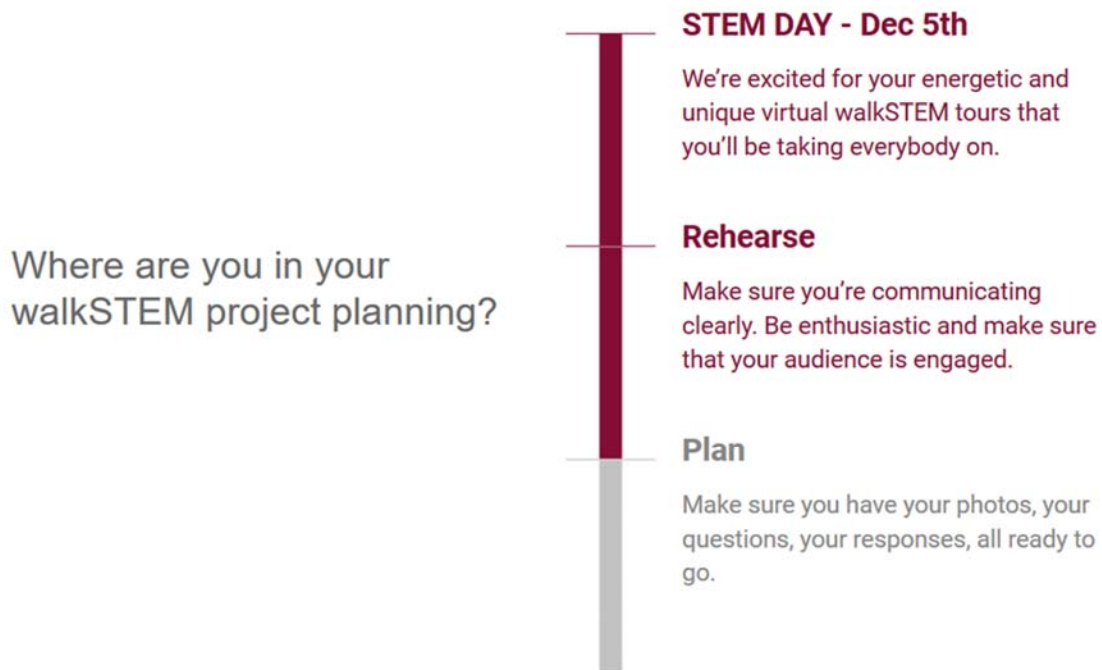   1) Is the tour related to a STEM course OR STEM topic you studied OR a place?
            2) Will you use #STEMlens photos OR short videos OR both?

You are all now at different places in your planning of a minimum of three stops each. You have all been working on a design worksheet for each of your three stops. We're going to go around to do a quick check in as to where you are in your planning.

For each stop, as many of you have been working on your design worksheets, you need to think about what you notice in each of the spaces you've decided to take your photos/videos in and your questions relating to math/science/STEM/STEAM. You also have had to pick a single question that you want to focus on for each stop and your response to that question. Finally, as you think about how you want to present on STEM day in two weeks, you can think about how you want to make interesting connections to other ideas, spaces, whatever comes to mind you think can make it fun and engaging for everybody who will be attending the event.

To kick off this Saturday session, please share your screen so that students can all look at the overview and chart on the next two pages. The goal is to spend not too much time on reminding everyone what you're working on and at the same time, getting your students motivated to complete their projects and have a wonderful presentation on Dec. 5th.

After you share the overview on the next page, you can have each student run through the chart on the following page. They should tell you exactly where they are in their planning for each of their three stops. Make a note as they speak so you know whom to help in what way.

Where are you in your walkSTEM project planning?

STEM DAY - Dec 5th

We're excited for your energetic and unique virtual walkSTEM tours that you'll be taking everybody on.

Rehearse

Make sure you're communicating clearly. Be enthusiastic and make sure that your audience is engaged.

Plan

Make sure you have your photos, your questions, your responses, all ready to go.

Let's check in on where you are!

	Stop#1	Stop#2	Stop#3

Notice			
Questions			
Selected Question			
Response			
Props/ Connections			

The goal for each student today:
- Completion of three design worksheets for three stops (these can be in note form)
- Completion of minimum of three #STEMlens photos/videos for the three stops
- Thinking through what connections, other visuals, etc. you might like to include in your presentation
- Rehearsal for STEM day

THIS IS THE FINAL LONG MEETING DAY WE HAVE BEFORE YOU PRESENT ON DEC 5TH.

Nov 30th to Dec 4th Lesson Plan

Note: this is the last session before the STEM Day presentation. Please use this time to help students finalize their scripts for their walkSTEM stops and make sure the presentation slides/videos are ready to go. **Please make sure the presentation slides/videos are uploaded to this folder (one set of slides per group):** <Link>

There is no specific tasks other than students working on their walkSTEM stops and rehearsing for the STEM day presentation.

By the end of today's walkSTEM session, each student should:
- Have finalized the #STEMlens photos/videos and scripts for the stops they are going to present on Dec. 5th.
- Know the order of presenting on Dec. 5th within the group and the slides should also be arranged accordingly.

Lesson Plan Details:
1. Go to the Zoom meetings and start recording:
    a. Go to the Zoom meeting.
    b. **Record the meetings locally if there is enough space on your laptop/PC.**
       (if not, record to cloud instead)

2. Finalize the walkSTEM stops
    a. See above to help students to get prepared for their presentations.
    b. For students who have already finished, let them write down the scripts under the "notes" section of the slides like this:
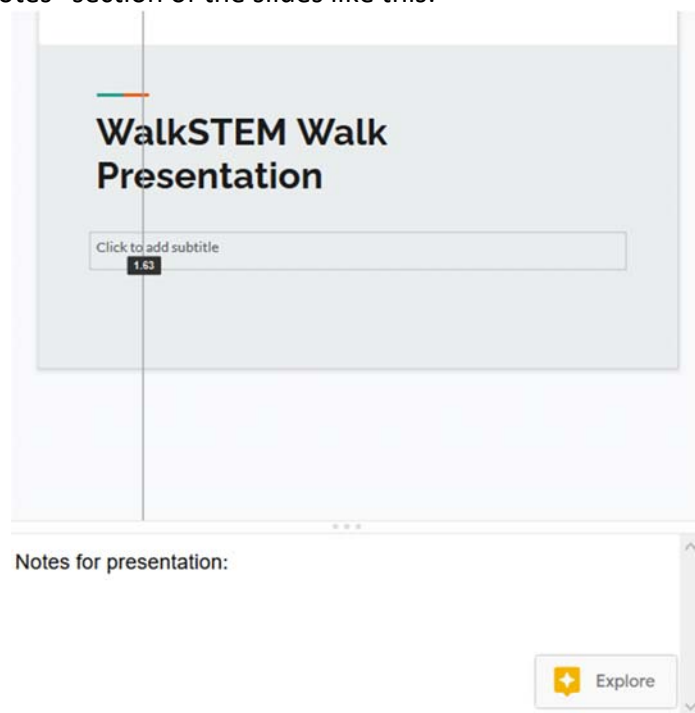
3. Wrapup (5 min)
    a. Remind students that they will have to complete **a post-survey after the presentation on Dec. 5th** (a similar one like the pre-survey but SHORTER since there is no solving problems session) and **they will get their $20 amazon gift card after submitting the post-survey.**
    b. Remind students that some of them will be **joining me (Min) on a different zoom link after they finished presenting and I'll conduct a short 15-min interview** with them. I'll finalize the interview **students' names by this week and send it to all tutors before Friday.**

Appendix D3: walkSTEM Tour Planning Sheet and Design Worksheet

<u>**walkSTEM Project Outline and Planning Sheet**</u>
What was interesting to you? What kinds of questions and what kinds of responses got you engaged? How did added connections to the key question keep you thinking?

Think also back to all the **#STEMlens** photos you created and that you viewed over the last several weeks. ***What types of mark-ups and questions made you feel most interested? What types of questions worked best? How did you avoid your question being too basic or "textbook-y"?*** You want each of your stops to feel unique, interesting, and also connect to other objects and ideas, where possible.
NOTE: You can connect arts and humanities ideas too, if relevant.

Your goal is to work with your partner to create a tour that consists of a total of 4 stops. You can plan your tour so each of you is responsible for 2 stops.

You can choose one of these themes for your walkSTEM tour:
The tour (consisting of a minimum of 3 stops) must revolve around a theme. A theme can be:
- 1 or more AP STEM or other STEM courses you are currently taking
- A STEM topic or concept that you are currently or have recently learned about
- A Place (e.g. your neighborhood, a park, your home, school campus, etc.)
- An Activity (e.g. a sport or hobby that requires being in the real world. Hobbies that involve screen-based interactions only are not permitted for this project)

What will your tour consist of? You have some choices!
OPTION 1: Using #STEMlens photos
- You may select some of the #STEMlens photos you already took **or** take new ones in order to create a walkSTEM tour that is around **one of the themes** listed below.
- If you choose to use #STEMlens photos, note that you may want to take some additional photos. You will probably want to include more than one angle or you may want to include some close-ups too. So, even if you are choosing to focus on a photo you already took, you may choose to take some additional photos.
OPTION 2: Using short videos
- You can create short (approx 2 min) videos using photos, voiceover, and personalized text.
OPTION 3: Using both #STEMlens photos and video
- You can create a tour where 1 or more stops use #STEMlens photos and 1 or more stops use video
FOR ALL 3 OPTIONS (using #STEMlens or using video to create your walkSTEM tour)
- Each tour must include 3 stops. You are required to have your stops focus on at least 2 of these 3 different kinds of locations or objects listed below. Your tour must cover at least 2 of these 3 different objects/spaces.
    - Built environment (building, statue, etc)
    - Natural environment (trees, plants, etc)
    - Artwork/everyday object

My walkSTEM Planning Sheet

My tour's theme
Place a check next to your selection:

_____ 1 or more AP STEM or other STEM courses you are currently taking

_____ A STEM topic or concept that you are currently or have recently learned about

_____ A Place (e.g. your neighborhood, a park, your home, school campus, etc.)

_____ An Activity (e.g. a sport or hobby that requires participating in the physical, 3D world. Hobbies that involve screen-based interactions only are not permitted for this project)

Describe and explain your reason for your selection:

What will my tour consist of?
Place a check next to the option you have selected
___ OPTION 1: Using #STEMlens photos
- You may select some of the #STEMlens photos you already took **or** take new ones in order to create a walkSTEM tour that is around **one of the themes** listed below.
- If you choose to use #STEMlens photos, note that you may want to take some additional photos. You will probably want to include more than one angle or you may want to include some close-ups too. So, even if you are choosing to focus on a photo you already took, you may choose to take some additional photos.

___ OPTION 2: Using short videos
- You can create short (approx 2 min) videos using photos, voiceover, and personalized text. If you select this option, write which video editing software you plan on using:
  _____
  _____

___ OPTION 3: Using both #STEMlens photos and video
- You can create a tour where 1 or more stops use #STEMlens photos and 1 or more stops use video.
  If you select this option, write which video editing software you plan on using:

_____
_____

Notes:

Design Worksheet: walkSTEM® Stop
Object and Location in the #STEMlens photo:
1. Notice – What do you observe in this object or space?
2. Questions – What do you wonder based on what you observed? Please list multiple questions here.
3. Curate – Which question from #2 above will you focus on in your walkSTEM? Rephrase the question if needed. Make sure the question is engaging and relevant.
4. Category - Which category does this question fall into (built environment, natural environment, artwork/everyday object/ other)?
5. Design – How will you virtual tour participants do while at this stop? Would you like to include some simple virtual "props" to make connections or provide examples (such as photos or models)?
6. Response - Please write a strategy/estimation/explanation to your question in #3.
7. Connection to school courses – What math, science, STEM, or STEAM course(s) is your question in #3 related to?
8. Connection to Math/Science – How is this observation/question centered on mathematical and/or scientific concepts in the real world.
9.(optional) Connection to Theme - If you are planning a theme-based walkSTEM tour, please address how each stop will help participants gain valuable experience that relates to your selected theme.

Appendix D4: walkSTEM Tour Training Mursion Simulation

WalkSTEM Tutor Training Mursion Simulation 1

HITS:

- Encourage the students to give feedback to each other

- Encourage students to use their "STEM Lens," and see math in things they wouldn't normally

- Helps the students locate additional resources (e.g., website on properties of dog eyes)

- Have students ask questions that are specific, that are interesting, that are answerable, and that related to math or science

- Refer the students to the rubric and discuss the rubric and what it means

- Get students to be engaged and feel safe; be excited about students' ideas

MISSES:

- Do not honor the students' opinions, ideas, and experiences

- Tell rather than question; Too controlling

- Ignore students' group members while talking to one student

- Being too focused on the math or science and its correctness

Simulation 1: In this simulation, 1 instructor is meeting with a small group of 3 students (Ava, Dev, Jasmine) via Google Hangouts. Each student was supposed to upload a "#STEMLens" photo to the discussion board on Canvas. When the simulation begins, the instructors have reviewed the students' photos are needing to give the students feedback. The students had been given this rubric to use when self-evaluating their own #STEMLens photos:

CATEGORY	5 Excellent	4 Good	3 Satisfactory	2 Needs Improvement	1 Below acceptable standards
Image + Markup	Image is clear and interesting. It is easy to see what aspect of the photo is the subject of the #STEMlens. The markup helps the viewer understand the photographer's perspective.	The image is clear and interesting. It is easy to see what aspect of the photo is the subject of the STEM lens. The markup is unclear or unspecific.	The image is clear and has some markup but the markup is messy and doesn't add any value to the photo.	Photo is taken and clear but has no markup.	Photo is blurry and has no markup.
Observation or Question	The observation/ question is specific and can be easily seen in the photo. It	The observation/ question relates to the photo but	The observation/ question relates to the photo but is more general.	It doesn't relate to the photo at all and the	The observation/q uestion is missing or

| | deals with something that can be visually seen in the photo itself, doesn't involve any processes/ concepts that are invisible. | is not specific (it is a more general observation/ question). It still involves a concept that can be readily seen. | However, it does not relate to the photo as well and may involve concepts that are invisible. | observation/que stion is unclear. | clearly lacking in quality |

Student 1 (Jasmine**):**

This student is enrolled in AP biology and is a 10th grader. She has uploaded a picture of her dog with a ruler and some mark-up, and the text "Ozzy's eyes are different from mine." Some issues with this (under the "Image and Markup" section of the rubric) is that the red circle is around Ozzy's whole head instead of the eyes. The inclusion of the ruler is a good idea though. Some issues with this under the "Observation or Question" section of the rubric is that the question (in blue text) is hard to see, and the question is not very specific – it is not clear what STEM processes or concepts are involved.

This student's personality is introverted but she takes feedback well. She struggles to reframe her question to be more related to science and math. Below is an example of how her photo could

theoretically be revised to be more in line with the goals of the walkSTEM program (the last word is cut off, but it says "see"):

From the internet: Because of the eyes' position on the front of the head—a sign of a predator rather than a prey animal, which has eyes farther apart—dogs have limited peripheral vision like humans do, and good depth perception. So the distance that your eyes are apart influences your peripheral vision and depth perception.

Some other good questions that could be asked are "How does the area of Ozzy's eye compare to the area of a human eye? How does this effect his vision?" or "How does the diameter of the circular part of Ozzy's eye compare to that part of my eye, and what does this mean for Ozzy dilating his pupil?"

[Note: if the tutor pauses to quickly google info about dog eyes either independently or with the student, this is great and is exactly the kind of interaction we want!]

Some questions that might not connect as well to AP Biology include: "How does the size/diameter/area of Ozzy's eye compare to the size of my eye?" "How does the distance been Ozzy's eyes compare to the distance between my eyes?"

Student 2 (Dev):

Dev is enrolled in AP Statistics and is a senior. He has uploaded the image from outside his apartment complex. The question reads "What data is there?" With respect to the "Markup" section of the rubric, the markup is hard to see because of the color. On the "Question" part of the rubric, the question ("What data is there?") is also hard to see and is not very specific. Dev really wants the tutor to tell him exactly what to do to fix his photo. He is not anxious to come up with his own question – he wants this to be like his math class in school where everything is close-ended and simple, with a "correct" or "incorrect" answer.

Below is an example of this picture being improved – the new question is: "How can we use how many grapes are in a small area of this bunch to predict how many grapes will be in the whole bunch?" Another good question would be: "How does the average number of grapes change as we go down the plant? Why might there be fewer grapes farther down" or "What is the average volume of a grape in this picture, and how much does it vary between grapes?"

Questions the student could pose that are less-related to AP Statistics are: "How many grapes are in the bunch?" or "How big is each grape in the bunch?"

Student 3 (Ava):

Ava is enrolled in pre-AP Geometry and is a junior. Ava did not upload a #STEMLens photo to the discussion board. If asked why, Ava will say she forgot and then also say that she didn't know what to do. She thinks she really doesn't have anywhere she can go to find math and science scenes, and she doesn't think she can do the assignment. She doesn't have any pets and she lives in an apartment building so she does not have a yard. She doesn't feel safe going around her neighborhood (she will not say this explicitly), and because of the pandemic her family really isn't going out in public at all. One approach the tutor could use with a student like this is to encourage them to take pictures in their house – like of the tiles in their bathroom or of a light fixture or fan. They could also encourage the student to look through past photos they've taken on their phone to see if one of them might work. In order for this student to be likely to do the assignment, the tutor will have to be really specific about next steps they should take, and be very encouraging.

General Notes about Simulation 1

- All three students have their cameras on in Google Hangouts; they cannot use the chat feature

- The students have all 3 of the submitted photos in front of them, and the students have the rubric in front of them.

- It is up to the tutor whether to have a relatively private conversation with each student, or whether to allow the students to discuss their photos and give feedback to each other. If the tutor does give the students the opportunity to give feedback to each other, they should be able to identify some of the issues described above, particularly issues with things being missing or hard to read. They have a harder time critiquing how good each others' questions are.

- One student may experience internet connectivity issues during the simulation.

- The students should not have any attitude/behavior problems.

WalkSTEM Tutor Training Mursion Simulation 2

In this simulation, the tutor is chatting one-on-one with Jasmine. She has her camera off. Sometimes she speaks out loud, sometimes she uses chat. In this simulation, the tutor is conferencing with a single student, and trying to support the student in turning one of their #STEMLens photos into a full STEM walk. The student must have 4 "stops" on their final math walk, around a single theme. The theme can be an activity they are interested in (e.g., basketball), a physical location (e.g., their backyard), a set of STEM concepts (e.g., angles), or an AP course (e.g., AP biology). To be turned into a STEM walk, the #STEMLens photos they use should be revised (if necessary) such that the questions are more authentic (i.e., questions that actual people would really want to figure out, and that there would be a larger purpose to figuring them out) and more interesting.

In this scenario, Jasmine (a 10th grader enrolled in pre-AP Geometry) has taken the following #STEMLens photo of a light fixture. She has been given the feedback that her question is not very authentic via a comment on Canvas from an instructor, and that it needs to be more authentic for her to use it for her walk. She has also been told that she needs to be able to provide an answer to her question, if she is going to use it for her walk. But she doesn't know how to improve her question or develop it into a whole walk:

What is this angle measurement?
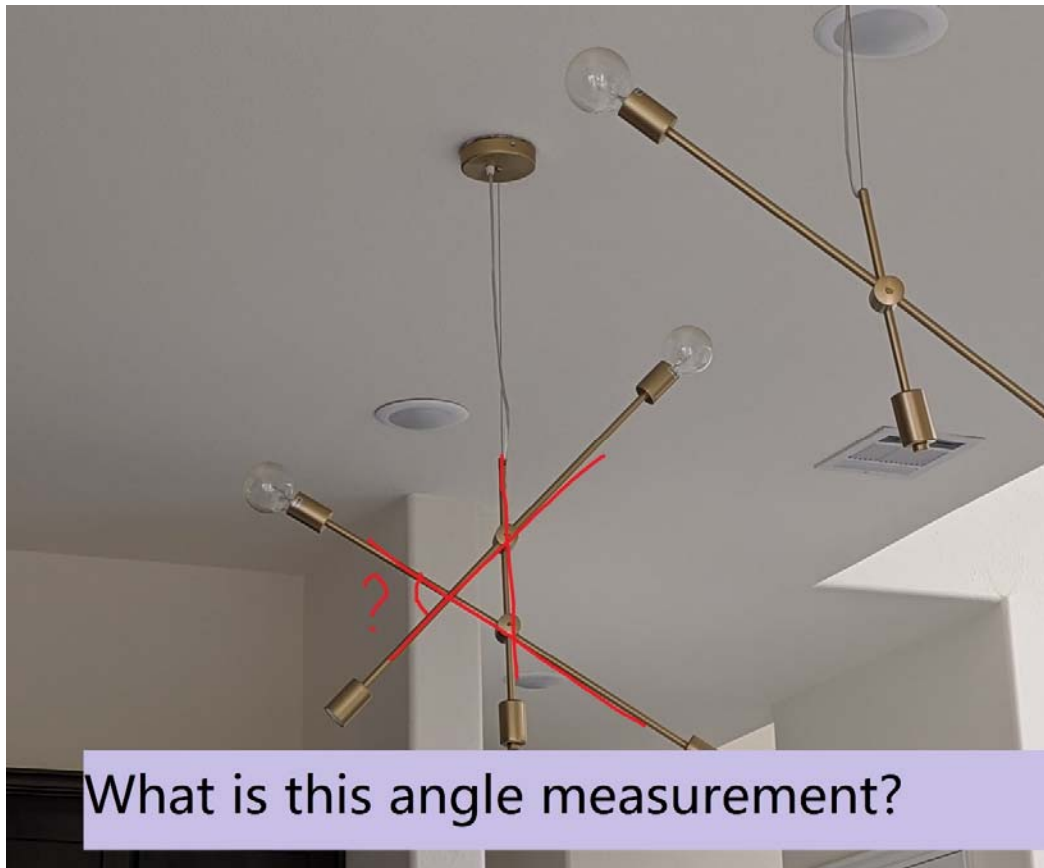
The question in this photo is very textbook-y, and not a realistic question someone might ask for an authentic purpose. A better question might be some part of: "Is the light fixture balanced around the center point? Is there the same length of rods on each side? Is there the same number of bulbs on each side?" A question relating to angles might be "Which angles are congruent in this picture, and why must they be congruent? If one angle was designed to be wider, what would happen to the other angle?"

For this to be a walk stop on the students' final walk, the student will also need to think about how they can provide *an answer* to their own question. If prompted, this student isn't sure how to answer the question she asked – how would they measure the angles? They are also not sure why anyone would want to measure the angles.

The student will also need help figuring out the theme of their walk if they want to use this photo – they could do a theme around angles, light fixtures, their home/the ceiling, etc. The stops will all need to relate to their STEM coursework in school. This student is more focused on the visual/art part and less on the math/science.

HITS:

- Give specific feedback

- Let the student talk

- Be excited about the students' photos and ideas

- Be patient when Jasmine is shy

MISSES

- Be too controlling or insert your own ideas too much

- Say you don't agree with the feedback or be negative about your own knowledge of geometry

- Walk away from the session without Jasmine having a concrete plan of action

- Criticize the way in which the student communicates with you (e.g., via chat)

Appendix E: Rubrics

Appendix E1: walkSTEM Project Rubric

walkSTEM Project Rubric

Part 1 Creativity and Quality of Content in #STEMlens photos/videos

CATEGORY	5 Excellent	4 Good	3 Satisfactory	2 Needs Improvement	1 Below Acceptable Standards
#STEMlens photos used in this walkSTEM tour	The #STEMlens photos on this tour include photos of each of these categories built environment, natural environment, artwork/everyday project and one other. All images and markups are excellent.	The walkSTEM planning sheet is completed but lacks detailed description about the theme of the tour and the plans to use the photos/videos to create the virtual tour.	The walkSTEM planning sheet is completed but only has a very vague description of the theme selection and the tour-making plan.	The walkSTEM planning sheet is only partially completed.	The walkSTEM planning sheet is missing.
#STEMlens Image + Markup (if the virtual tour uses photos)	Image is clear and eye-catching. It is easy to see what aspect of the photo is the subject of the #STEMlens. The markup helps the viewer understand the photographer's perspective.	The image is clear and eye-catching. It is easy to see what aspect of the photo is the subject of the #STEMlens. The markup is unclear or unspecific.	The image is clear and has some markup but the markup is messy and doesn't add any value to the photo.	Photo is clear but has no markup.	Photo is blurry or non-specific and has no markup.
walkSTEM Video (if the virtual tour uses a video)	The video is of good quality and the content of the video is eye-catching. It is easy to see the objects that this walkSTEM video is about. The voice-over explained the STEM objects in the video and helps the viewer understand the authors' perspective.	The video is of good quality and the content of the video is eye-catching. It is easy to see the objects that this walkSTEM video is about. The voice-over introduced the STEM objects in the video but the explanation of the objects is unclear or unspecific.	The video is of good quality. It is unclear what the objects that this walkSTEM video is about. The voice-over doesn't provide any useful information to the video or there is no voice-over.	The video is of good quality but there is no voice-over or editing to the video that shows what the STEM objects in this video are.	The video is blurry or non-specific and there is no voice-over or editing to the video that shows what the STEM objects in this video are.

Part 2 walkSTEM Tour Planning and Design

CATEGORY	5 Excellent	4 Good	3 Satisfactory	2 Needs Improvement	1 Below Acceptable Standards
walkSTEM Tour Planning Sheet	The walkSTEM planning sheet is completed and has detailed description about the theme of the tour and the plans to use the photos/videos to create the virtual tour.	The walkSTEM planning sheet is completed but lacks detailed description about the theme of the tour and the plans to use the photos/videos to create the virtual tour.	The walkSTEM planning sheet is completed but only has a very vague description of the theme selection and the tour-making plan.	The walkSTEM planning sheet is only partially completed.	The walkSTEM planning sheet is missing.
walkSTEM stop #1 Design sheet	The design worksheet is completed and the responses to all entries are reasonable and thorough.	The design worksheet is completed the responses to all entries are thorough but some of the responses are not reasonable or feasible (i.e., the strategy/estimation/explanation to the question; the connection to your courses etc.)	The design worksheet is completed but some of the responses to the design sheet entries are unspecific or vague.	The design worksheet is only partially completed which means some of the responses to the design sheet entries are missing.	The design worksheet is missing.
walkSTEM stop #2 Design sheet	see above	see above	see above	see above	see above
walkSTEM stop #3 Design sheet	see above	see above	see above	see above	see above
walkSTEM stop #4 Design sheet (opt)	see above	see above	see above	see above	see above
walkSTEM Presentation	The walkSTEM presentation is well prepared and the tour is interesting. The author uses the #STEMlens photos/videos and questions/observations to engage the audience to the wakSTEM tour.	The walkSTEM presentation is well prepared and the tour is interesting. The author uses the #STEMlens photos/videos and questions/observations to present but the presentation is lack of audience participation.	The walkSTEM presentation is well prepared. The author uses the #STEMlens photos/videos and questions/observations to present but there is obvious incoherence in the tour presentation.	The walkSTEM presentation is not well prepared. The author uses fewer than three #STEMlens photos/videos or the questions/observations are missing.	The walkSTEM presentation is missing.

Appendix E2: #STEMlens Rubric

#STEMlens Rubric					
CATEGORY	5 Excellent	4 Good	3 Satisfactory	2 Needs Improvement	1 Below acceptable standards
Image + Markup	Image is clear and eye-catching.. It is easy to see what aspect of the photo is the subject of the #STEMlens. The markup helps the viewer understand the photographer's perspective.	The image is clear and eye-catching. It is easy to see what aspect of the photo is the subject of the #STEMlens. The markup is unclear or unspecific.	The image is clear and has some markup but the markup is messy and doesn't add any value to the photo.	Photo is clear but has no markup.	Photo is blurry or non-specific and has no markup.
Observation or Question	The observation/ question is specific and refers to something that can be seen in the photo itself. , It does not involve any processes/ concepts that are invisible or not present in the photo.	The observation/ question relates to the photo but is not specific (it is a more general observation/ question). It still involves a concept that can be readily seen.	The observation/ question relates to the photo but is non-specific. It may involve concepts that are invisible or not present in the photo.	The observation/question does not relate to the photo at all and the observation/question is unclear.	The observation/question is missing or clearly lacking in thought or planning.

Appendix F: Student Pre- and Post-Survey

1. <u>Pre- Only:</u>

1) What is your race/ethnicity?

2) What is your gender?

3) What languages are spoken in your home?

4) How old are you?

5) Which grade level are you in?

6) What school do you go to?

7) What math class or classes are you taking right now?

8) What grade do you typically make in your math classes?

9) What career are you interested in?

10) Do you plan to go to college? Where?

11) What do you plan to major in, when you go to college?

12) What's your favorite subject in school?

13) What are some of your interests or hobbies?

14) Do you have any experience creating your own math problems?

    D. Yes, I have created math problems before.

    E. I have only created problems in other subjects, not math.

    F. No, I don't have experience in creating problems.

15) What experience do you have creating your own custom videos or with video editing?

2. <u>Pre- and Post</u>

3.1	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1) Math is practical for me to know.					
2) Math helps me in my daily life outside of school.					
3) It is important for me to be a person who reasons mathematically.					
4) Thinking mathematically is an important part of who I am.					
5) I enjoy the subject of math.					
6) I like math.					
7) I enjoy doing math.					
8) Math is exciting to me.					

3.   <u>Post- Only</u>

1. Do you like creating your own math problems in this program? Why or why not?

    _____

2. What suggestions do you have for teachers or students who are going to participate in future

    walkSTEM programs?

    _____

3. <u>Procedural Fluency, Conceptual Understanding, and Problem-Solving (pre- only)</u>

1. (Number, Item#M032094)

    $$\frac{4}{100} + \frac{3}{1000} =$$

    A. .043
    B. .1043
    C. .403
    D. .43

2. (Number, Item#M032166)

    Which of these is the BEST estimate of $\frac{7.21 \times 3.86}{10.09}$?

    A. $\frac{7 \times 3}{10}$
    B. $\frac{7 \times 4}{10}$
    C. $\frac{7 \times 3}{11}$
    D. $\frac{7 \times 4}{11}$

3. (Number, Item#M042002)

    Place the four digits 3,5,7, and 9 into the boxes in the positions that would give the greatest result when the two numbers are multiplied.

4. (Algebra, Item#M032205)

There were *m* boys and *n* girls in a parade. Each person carried 2 balloons. Which of these expressions represents the total number of balloons that were carried in the parade?
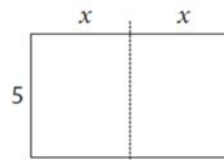A. $2(m + n)$
B. $2+(m + n)$
C. $2m + n$
D. $m + 2n$

5. (Algebra, Item#M032419)
   Which of these could represent the expression $2x +3x$

   A. The length of this segment:

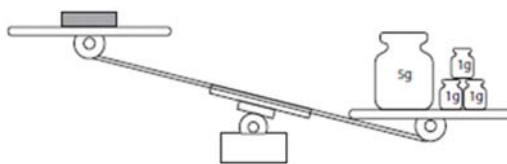   B. The length of this segment:
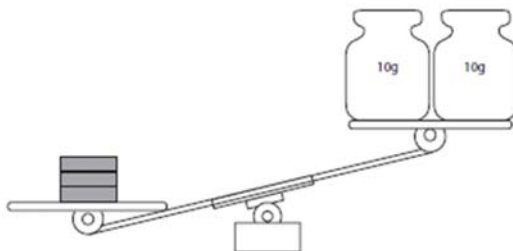   C. The length of this segment:
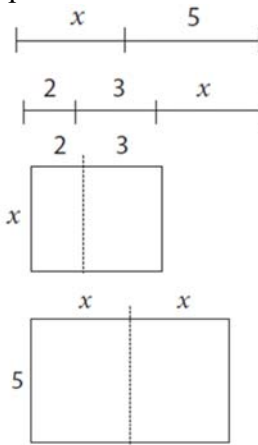
   D. The length of this segment:

6. (Algebra, Item#M032424)
   Jo has three metal blocks. The weight of each block is the same. When she weighed one

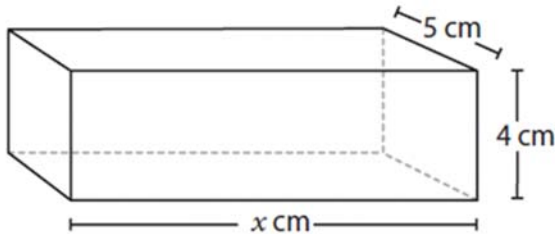   block against 8 grams, this is what happened.

   When she weighed all three blocks against 20 grams, this is what happened.

   Which of the following could be the weight of one metal block?

    A. 5g
    B. 6g
    C. 7g
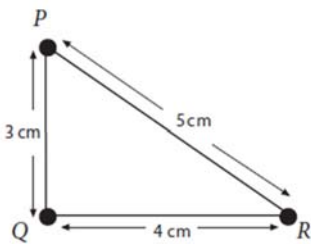   D. 8g

7. (Geometry, Item#M042201)

The volume of the rectangular box is 200 cm³. What is the value of x?
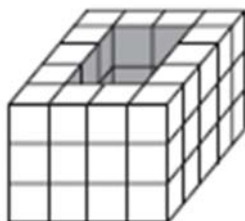
Answer: _____

8. (Geometry, Item#M032402)

Which of these is the reason that triangle PQR is a right angle triangle?

A. $3^2 + 4^2 = 5^2$
B. $5 < 3+4$
C. $3+4=12-5$
D. $3 > 5-4$

9. (Geometry, Item#M032100)
The figure above shows a shape made up of cubes that are all the same size. There is a

hole all the way through the shape. How many cubes would be needed to fill the hole

(Item#M032100)?

A. 6
B. 12
C. 15
D. 18

10. (Data)There are 25 girls in a class. The average height of the girls is 130 cm.
    10.1 (Item#M421Q01) Explain how the average height is calculated.
    10.2 (Item#M421Q02) Circle either "True" or "False" for each of the following
        statements.

Statement	True or False
If there is a girl of height 132 cm in the class, there must be a girl of height 128 cm.	True/False
The majority of the girls must have height 130 cm.	True/False
If you rank all of the girls from the shortest to the tallest, then the middle one must have a height equal to 130 cm.	True/False
Half of the girls in the class must be below 130 cm, and half of the girls must be above 130 cm.	True/False

    10.3 (Item#M421Q03) An error was found in one student's height. It should have been

120 cm instead of 145 cm. What is the correct average height of the girls in the class?

        A. 126 cm
        B. 127 cm
        C. 128 cm
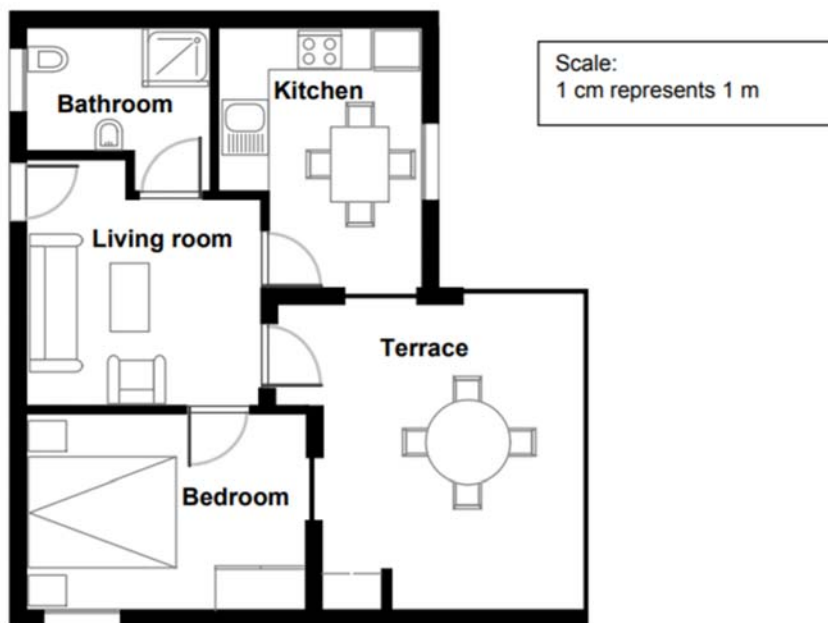   D. 129 cm

5. Problem-Posing (pre- and post-)

1) Describe the mathematical ideas you see in this picture. What questions might you pose

based on this picture?

2) Describe how you see math in your home or neighborhood. Give at least 2 examples.

3) This is the plan of the apartment that George's parents want to purchase from a real estate agency.

Pose a mathematical problem based on this apartment floor plan or this apartment buying scenario.

Appendix G: Student Interview Protocol

I appreciate you letting me interview you for the research. I have some questions for you about

the walkSTEM program that you attended. I will record this interview and the interview will

only be used for this research.

- **Part 1: Background Information**
  - Which grade level are you in?
  - What's your favorite subject in school?
  - What are some of your interests or hobbies?
  - Why did you choose to attend this walkSTEM program?
- **Part 2: Disposition Toward Problem Posing**
  - Do you have any experience of creating mathematical problems before attending this program?
  - How do you like the process that you create your own problems in this program?
  - What are some of the challenges that you encountered when creating your own problems?
  - Can you describe one specific example that you created a problem that you really liked creating in this program?
  - How do you think your experience of creating the math walk in this program will impact your mathematical learning in the future?
- **Part 3: About the online walkSTEM program**
  - How much do you like participating in the walkSTEM program?
  - How did you like the experience of creating your own virtual math walk?
  - What is the part that you like the most and the least in this program?
  - Compared to when you first began this program, has your interests or attitudes about mathematics changed? If so, can you explain how and why?
  - How do you think attending this walkSTEM program online instead of having in-person meetings has impact your experience of participating in these activities?
  - What suggestions do you have for this program if we are going to run this next year?
- **Part 4: Wrap Up**
  - Finally, is there anything else you want to share with me about your experience with this walkSTEM program?

Thank you so much for attending this interview! Your opinion is really important for our

study.

Appendix H: Instructor Interview Protocol

1. **Prior-Intervention Interview:**
   - **Part 1: Teaching Background**
     - o How long have you been teaching or tutoring?
     - o Which grade levels and subjects do you teach or tutor?
   - **Part 2: walkSTEM and Problem Posing Background**
     - o Have you been participating in any walkSTEM or talkSTEM events or programs before? If so, please describe the events or programs.
     - o What do you think might make the walkSTEM program different from other STEM instructional programs?
     - o Problem-posing refers to the broad-based, inquiry oriented process in which students generate new mathematical problems or re-formulate given problems and can happen before, during, or after problem solving. Do you have any experience with problem posing activities?
     - o What is your disposition or understanding toward students' problem posing?
     - o How do you think problem posing might impact students' STEM learning?
     - o What challenges or difficulties do you foresee in this walkSTEM program?
2. **During-Intervention and Post-Intervention Interview:**
   - **Part 1: Program Planning**
     - o What resources did you use to plan for this walkSTEM program? Are those the resources you typically use?
     - o Could you please tell me about a time you use the resources for planning?
     - o Except for the lesson plans that the researchers provided, did you receive any support from other teachers/tutors in the College Access Program? If so, can you describe the support to me?
   - **Part 2: Student Behavior**
     - o Did you notice any change in the students' learning behavior at this point compared to the beginning of this program?
     - o Did you notice any change in the students' problem posing performance at this point compared to the beginning of this program?
     - o Did you notice any change in the students' attitudes or dispositions toward this program or STEM learning in general?
   - **Part 3: Instruction**
     - o Now that you have some experience with walkSTEM and problem-posing, I'm curious how you feel about problem posing?
     - o When do you think problem-posing is useful?
     - o For what purpose do you think problem-posing should be used in teaching?
     - o Do you think problem posing should be included in other STEM teaching? Why?
     - o Have you found that your experience in this program has influenced your other instruction? How? (Please provide a specific example)
   - **Part 5: Wrap up**
     - o Is there anything else you want to share with me regarding your experience leading this program?
     - Thank you again for participating in this interview!