Enhancing STEM Learning in Pre-K-12 Education: A Multifaceted Approach to Supporting Students and Training Teachers

by

Hannah Smith

A Dissertation

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Doctor of Philosophy

in

Learning Sciences & Technologies

April, 23, 2023

APPROVED:

Erin Ottmar, Ph.D., Worcester Polytechnic Institute

Gillian Smith, Ph.D., Worcester Polytechnic Institute

Stacy Shaw, Ph.D., Worcester Polytechnic Institute

Paul Reimer, Ph.D., AIMS Center

Abstract

STEM skills are predictive of later success. Specifically, early math skills predict later math achievement. Further, children who have access to research-based STEM learning activities show higher levels of STEM achievement. However, teachers still spend the majority of time on subjects other than STEM subjects and many students enter school with lower science and math scores than other subjects. To address this problem, it is important to consider multiple facets of education; these include students and the systems they use in learning as well as teachers and how they are trained to effectively implement STEM activities in the classroom. As Pre-K-12 education is continuing to rely more and more on virtual platforms to assist in learning, it is important to study what support we can provide to students within these online settings to increase their math learning. This manuscript-style dissertation focuses on both the student and teacher aspects of STEM learning, through three studies. The first two studies explore how we can support students as they complete online Math assignments. The final study focuses on how we can improve teacher attitudes and confidence toward STEM teaching and explores how teachers implement STEM activities from a professional development program.

Chapter 1. Introduction

STEM skills are predictive of later success (Clements & Sarama, 2016; Denton & West, 2002). Specifically, early math skills predict later math achievement (Clements & Sarama, 2016; Duncan et al., 2007). Further, children who have access to research-based STEM learning activities show higher levels of STEM achievement (Clements& Sarama, 2016). However, teachers still spend the majority of time on subjects other than STEM subjects and many students enter school with lower science and math scores than other subjects (Clements & Sarama, 2016). Additionally, as Pre-K-12 education is continuing to rely more and more on virtual platforms to assist in learning, it is important to study what support we can provide to students within these online settings to increase their math learning. To address these problems, it is important to consider multiple facets of education; these include students and the systems they use in learning as well as teachers and how they are trained to effectively implement STEM activities in the classroom. This manuscript-style proposal focuses on both the student and teacher aspects of STEM learning, through three studies.

The first two chapters of this dissertation share two studies aimed at identifying student supports within online learning platforms which can aid in middle and high school math learning. The first chapter shares a published manuscript that explores which types of worked examples are most effective in supporting student algebra practice and learning within an online homework platform. The second chapter shares a published conference proceeding, and in-preparation manuscript, which explores how mental rotation knowledge interacts with problem presentation and hints in an online homework platform. These studies provide evidence that supported practice in online learning platforms leads to increases in learning. They also present different forms of support which can be provided to students within these online learning platforms that can aid in learning. Importantly, they show that the effects which we see in laboratory and on paper in-classroom studies hold true within online learning platforms across schools, teachers, and students, adding to the literature on mental rotation effects and the worked example effect and broadening their impact to an online learning environment.

While it is important to identify ways to support students in middle and high school as they practice math learning on online platforms, there are disparities between future success that can be identified through early preschool and kindergarten experiences and success at the preschool and kindergarten level (Clements & Sarama, 2016; Denton & West, 2002; Duncan et al., 2007; National Research Council, 2013). Therefore, it is also important to explore access to and experiences with STEM learning at an earlier level. Teachers also play an important role in these early experiences, but often lack the training and positive attitudes, and self-efficacy to implement STEM activities successfully contributing to less frequent use of STEM activities compared to literacy activities in preschool (Clements & Sarama, 2016). The third study in this dissertation explores a six-month professional development program aimed at teaching STEM activities to Head Start preschool teachers. I explore how teachers implement and expand the STEM activities in their classrooms and how their overall attitudes and confidence towards STEM teaching change as a result of the professional development program.

Project 1: The impact of algebra worked example presentations on student learning

The manuscript, "The Impact of Algebra Worked Example Presentations on Student Learning" (Smith, Closser, Ottmar, & Chan, 2022) which is published in *Applied Cognitive Psychology*, explores how different presentations of worked examples influence learning among Algebra 1 students. Students saw one of six different presentations of worked examples differing in the detail of the worked example (concise vs. extended) as well as the dynamicness of the worked example (static, sequential, or dynamic). We found that students improved their algebra problem-solving performance in all conditions. These results suggest that regardless of presentation format, worked examples are a form of effective learning support for Algebra 1 students. Since students showed improvement independent of presentation format, this opens the door for students to have some autonomy in choosing which worked example format they view, as well as teachers to use different worked example formats.

Project 2: Can Mental Rotation Predict Performance in an Online Geometry Assignment?

While the first study explored how supports in an online homework platform can affect algebra learning, the second study expands on this by exploring supports within a geometry context; specifically on translation and rotation problems. Specifically, this study explores student support in an online learning environment. The support presented to students was presented in the design and presentation of the specific problem. Some students saw problems that were presented in a way to encourage analytical problem-solving practices and some saw problems presented in a way to encourage visuospatial problem-solving practices, which we propose would rely on spatial skills more. In addition, this study includes measures of mental rotation to explore how related skills can affect performance. The published conference proceeding, "Can Mental Rotation Predict Performance in an Online Geometry Assignment?" (Smith, Ramey, Uttal, & Heffernan, 2022) and in-prep manuscript explores how mental rotation knowledge and problem presentation predicts performance in two different online geometry problem sets as well as how mental rotation knowledge moderates the effect of problem presentation. We found that problem presentation has no effect on performance, but that mental rotation is a strong predictor of performance regardless of the topic of geometry (rotations; translations). This confirmed the effect of mental rotation on geometry performance and extended the effect to an online learning environment. Further, we showed that the way a problem is presented has little effect on student performance.

Project 3: Assessing Preschool Teacher Self-Efficacy and Attitudes Toward STEM Through the Implementation of a Professional Development Program

While the first two studies in this proposal focus on student aspects of learning, the third project shifts the focus from the student aspect of STEM learning to the teacher aspect. In addition, the first two projects focus on middle and early high school students, while the third project shifts the focus to a preschool context. I have worked with a team to design, implement and assess a 6-month professional development program focused on introducing STEM activities and concepts to Head Start preschool teachers, as well as improving their confidence and attitudes toward STEM teaching. We explore how teachers' confidence and attitudes towards STEM have shifted throughout the program as well as how they were able to expand and implement the activities from the program in their classrooms. The first two studies in this proposal use strictly quantitative methods, while this study employs a qualitative approach.

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Smith, H., Closser, A. H., Ottmar, E., & Chan, J. Y. C. (2022). The impact of algebra worked example presentations on student learning. Applied Cognitive Psychology, 36(2), 363-377. https://doi.org/10.1002/acp.3925

Ch. 2 The Impact of Algebra Worked Example Presentations on Student Learning

This chapter presents the pre-print version of the following manuscript:

Smith, H., Closser, A. H., Ottmar, E., & Chan, J. Y. C. (2022). The impact of algebra worked example presentations on student learning. *Applied Cognitive Psychology, 36*(2)*, 363-377*. https://doi.org/10.1002/acp.3925

Abstract

Worked examples are effective learning tools for algebraic equation solving. However, they are typically presented in a static concise format, which only displays the major derivation steps in one static image. The current work explores how worked examples that vary in their extensiveness (i.e., detail) and degree of dynamic presentation (i.e., static vs. sequential line-by-line vs. dynamic format that demonstrates the problem-solving process) impact learning. We conducted an online experiment in which 230 algebra students completed a pretest, studied worked examples in one of six presentation conditions, and completed a posttest. We found that overall, students improved from pretest to posttest after viewing the worked examples; we did not find significant differences in posttest performance between worked example presentations. These results have implications for the design of worked examples in online tutoring systems as well as for cognitive load theory and perceptual learning theory in the design of worked examples.

Keywords: algebra, cognitive load theory, online learning, perceptual learning, worked examples

The impact of algebra worked example presentations on student learning

When students learn new procedures in mathematics, they may struggle to apply these procedures correctly during equation solving. For Instance, students may still struggle to correctly distribute to all terms within parentheses even after being taught the procedure for distribution. In cases like these, worked examples can be used as a tool for learning by providing the derivations to mathematics problems; they also explicitly break down a given problem step-by-step to show one way of correctly solving the problem. Worked examples have proven to be effective instructional support in a broad range of subjects(e.g., language: Lu et al., 2020; chemistry: McLaren et al., 2016; statistics: Tempelaar et al., 2020) and specifically in algebra (Atkinson Et al., 2000; Barbieri & Booth, 2020; Booth et al., 2013; Carroll, 1994; Renkl, 2014). Prior research on worked examples has mostly presented static concise derivations of problems in which worked examples are displayed as an image of the major derivation steps (Booth et al., 2013; Rittle-Johnson et al., 2009; Star et al., 2015). However, it is unclear whether static concise worked examples are the most effective presentation to support student learning since limited research has investigated the impact of different worked example presentations. Further, with the introduction of new technologies, we can now dynamically interact with algebraic symbols, and alter the visual for-mat and perceptual features of worked examples effortlessly at scale. As more teachers incorporate educational technologies in their classroom instruction, it is important to explore how these technologies provide affordances for presenting worked examples, and how different presentations of equation-solving processes may help students learn and practice algebra in online learning platforms. We aim to add to existing research on worked examples by investigating the effects of different features of the worked example on algebra learning in an online environment. In particular, we explore whether students benefit more from viewing concise or extended worked examples, varying in the length and detail of problem derivation. We also explore whether students benefit more from viewing worked examples that are static images, worked examples that provide sequential presentations of derivation steps in a looping video, or worked examples showing the dynamic process of solving an equation with an online algebra notation tool in a screen-recorded video. Building on cognitive load theory (Sweller, 1994) and perceptual learning theory (Gibson, 1969), this study aims to contribute a richer understanding of how viewing different worked example presentations impacts student learning and to provide recommendations for online tutoring systems which use worked examples for algebra instruction.

Traditional Worked Examples

The benefits of using worked examples in algebra have been examined over the past few decades (e.g., Sweller & Cooper, 1985; see Atkinson et al., 2000, for a review) with much of the research focusing on the impact of worked examples on learning and the methods for implementing worked examples. Carroll (1994) found that algebra students who were given worked examples with practice-paired problems learned quicker, with less instruction, and made fewer errors during practice compared to their counterparts who practiced solving problems without worked examples. In another study, Boothet al. (2013) explored Algebra I students' performance in an online learning platform. Students either viewed worked examples and solved practice problems or only solved problems in the program. The Students who viewed worked examples outperformed the students who only practiced solving problems on measures of conceptual knowledge of algebra. Similarly, Foster et al. (2018) confirmed that undergraduate students who received worked examples followed by problem-solving outperformed those who only practiced problem-solving. Together, these studies show that worked examples lead to more efficient and effective student learning than solving problems alone. However, it is important to note that the worked example mate-rials in these studies are all static images that display the major derivations of each problem solution. Extending prior work and drawing from the cognitive load theory, we examine how worked example presentations—specifically how extensive or dynamic they are—may impact algebra learning in an online environment among middle and high school students.

Cognitive Load Theory

Worked examples are considered to be an effective tool for learning because viewing worked examples reduces the cognitive load that is placed on students when problem-solving (Sweller, 1994). Providing a step-by-step example to reference frees up working memory and gives students more cognitive space for learning. As a result, students are more likely to learn from worked examples than from problem-solving alone, which is known as the worked example effect(Sweller, 2006). Research has shown that the effect of worked examples on learning varies by students' prior knowledge (Renkl, 2014). For example, Kalyuga et al. (2001) found that students with lower prior knowledge benefited more from worked examples whereas students with higher prior knowledge benefited more from problem-solving. However, the relationship between prior knowledge and the use of worked examples varies by the worked example format. For example, when worked examples contain errors, only students with sufficient prior knowledge benefit from them (Grobe & Renkl, 2007). Together, these findings suggest that learners with different levels of prior knowledge may benefit differently from differing formats of worked examples and that learners with lower prior knowledge may benefit more from worked examples with more explicit instruction. In order for worked examples to be most effective for learning, it is important to consider whether and how the presentation format and visual features of worked examples increase or decrease learners' cognitive loads. Although worked examples are an effective instructional tool, the presentation of worked examples and instructional materials has been shown to impact learning gains and cognitive load(Sweller, 2020; Sweller et al., 2019). For instance, students who viewed on-screen text that duplicated an audio explanation of how lightning forms scored lower on retention and knowledge transfer compared to their counterparts who did not view extra on-screen text, likely due to cognitive overload (Mayer et al., 2001). These findings have led to guidelines for creating worked examples, such as minimizing extraneous complexity, avoiding stimuli that split students' attention or provide redundant information, and drawing attention to the subgoals of the problem (Schwartz et al., 2016; Sweller, 2020; Sweller et al., 2019). While worked examples may reduce students' cognitive load, it remains unclear which features of worked examples impact students' cognitive load during algebra learning. We examine how extensive(i.e., how detailed) worked examples should be to maximize algebra learning. Research on element interactivity—the number of elements that are simultaneously processed in working memory—in worked examples has shown that students learn more from scaffolded instruction over time. Specifically, students benefit from studying worked examples that present problem elements sequentially instead of simultaneously, which have higher element interactivity and ask students to make connections while studying (Lu et al., 2020). Prior work with college students has also demonstrated that students outperform their peers on near and far transfer items after viewing worked examples, which present information sequentially, rather than simultaneously (Lusk & Atkinson, 2007). Further, novice learners benefit from exposure to worked examples that show extensive details between each step before studying worked examples that only show the major steps in an industrial skills course (Pollock et al., 2002), although less is known about how algebra students may benefit from different degrees of detail in worked examples. Because prior research has focused on the effects of concise worked examples on learning, it is unclear how much detail is ideal to present in a worked example. On one hand, concise worked examples may help focus students' attention and avoid cognitive overload; on the other hand, extensive worked examples may help students offload the steps between major derivations onto the screen, and explicitly connect these derivations in the worked examples.

Worked Examples in Online Learning Environments

Prior work has shown that worked examples in online learning environments, such as tutoring systems, are effective at increasing instructional time and increasing learning (Salden et al., 2010). Therefore, it is important to consider how to effectively present worked examples to students as well as leverage the affordances of technologies for learning in online environments. Different from traditional learning with pencil and paper, one unique affordance provided by educational technologies is the ability to create worked examples with dynamic perceptual features for online viewing. With the affordances of technologies, it may be worthwhile to consider designing worked examples from a cognitive perspective other than cognitive load. Prior research on perceptual learning has shown that individuals rely on visual cues in mathematics materials; consequently, using visual cues to direct students' attention to relevant information can support their cognitive processes and increase learning (Gibson, 1969; Goldstone et al., 2017; Kirshner, 1989). For Example, Harrison et al. (2020) showed that subtle manipulations of the spacing between terms in a mathematics problem could help guide learners to the correct calculations while problem-solving. Similar Research has demonstrated the impact of spatial grouping on students' problem-solving performance, providing evidence that minute visual features in instructional materials can impact student performance(Braithwaite et al., 2016; Landy & Goldstone, 2007, 2010). Extending Beyond altering visual features in static equations, educational technologies allow us to guide students' attention to important information through motions they study worked examples with dynamic features. Dynamic educational technologies such as Desmos (Ebert, 2014)and Graspable Math (Weitnauer et al., 2016) allow users to manipulate linear equations, graphs, and expressions, and see the outcomes of their actions in real time on their computer screens. As interactive educational technologies like these become increasingly common, it's also possible to provide students with worked examples that demonstrate the dynamic process of solving algebraic equations (e.g., in3x=6, dragging 3 across the equal sign initiates the inverse operation and divides both sides by 3). Previous studies have shown the effectiveness of watching videos or animations of experts solving problems and providing explanations in an online environment (e.g., Wouterset al., 2008). These animations provide attentional cues, such as highlighting and motion, for students so that they can attend to the right information at the right times (Ayres & Paas, 2007; Deet al., 2009)

Current Study

Most prior research presents worked examples to students in a static fashion that displays the major steps taken to solve a problem. However, with new technology and interactive tools, we posit that there may be ways to leverage the affordances of technology in order to present worked examples that help students learn effectively in online environments. We explore these different presentations of worked examples through the lenses of cognitive load theory and perceptual learning theory by manipulating features of worked examples. We aim to determine whether cognitive load theory, perceptual learning theory, or a combination of both will provide the best explanation for how different presentation formats of worked examples impact student learning in algebra. In this study, we vary worked example presentations to experimentally test their effects on learning and to identify elements of worked examples that are effective for learning (pre-registered with SREE under Registry ID #1905.1v1). To account for the potential effect of students' prior knowledge when exploring how different levels of detail and dynamics impact learning, we recruited AlgebraI students who were still learning to solve equations and controlled for students' prior knowledge in the analyses. We compare posttest performance among middle and high school algebra students who complete an online problem set in one of six conditions that vary in the extensiveness and dynamicness of worked example presentations. In the current study, we utilize images or videos of worked examples made using Graspable Math (GM), a freely available interactive algebra notation tool, to explore the potential benefits of showing the process of equation-solving through dynamic worked examples. Because dynamic worked examples animate actions involved in each step of the derivation, they may provide perceptual cues to the relevant information at the right time as students view the worked examples. In a randomized controlled study conducted in the ASSISTmentsplatform (Heffernan & Heffernan, 2014), we compare the effect of traditional static worked examples to sequential and dynamic worked examples among middle and high school students. We include worked examples that present the derivation steps line-by-line in sequential order as an intermediate comparison between fully static and fully dynamic worked examples. We hypothesize that the dynamic worked examples may provide learners with additional perceptual cues above and beyond static and sequential worked examples, allowing them to clearly follow the connections between derivation steps. Additionally, we compare concise and extended versions of traditional static worked examples (displaying complete derivations in one image) and sequential worked examples (showing derivations line by line in a looping GIF video), as well as two versions of dynamic worked examples (where screen recordings were made as equations were manipulated and transformed in GM and displayed as a looping GIFvideo) that vary in the amount of information presented on screen. We hypothesize that while extensive worked examples may provide more information, concise worked examples may be more beneficial for learning by minimizing the content on the screen. Based on both cognitive load theory and perceptual learning theory, we hypothesize that students who view the concise and dynamics worked examples may demonstrate higher performance on the posttest compared to students in other conditions. Based on cognitive load theory, concise worked examples that only present the major derivation steps may reduce students' cognitive load as they learn from worked examples. Based on perceptual learning theory, dynamic worked examples that animate problem-solving processes may provide the most perceptual support for students as they view worked examples.

Methods

Participants

Participants were recruited from the ASSISTments teacher community through a monthly newsletter for teachers interested in supporting research through the ASSISTments platform. We provide a brief description of the study as well as a link to the problem set for teachers to assign to their Algebra I students in seventh to twelfth grade. A total of 25 teachers located in North America or Central America expressed interest and assigned the problem set to their students between October 2019 to March 2021. A total of 454 students started the assignment while only 300 completed the pretest and 230 completed the entire problem set. We note that 29 data points were excluded from analyses due to data logging errors, thus the final analytic sample comprised 230 students who completed the problem set and did not have data logging errors. Of the students who started the problem set, only 51% completed the problem set. The completion rate was relatively low but comparable to that of other research studies conducted in ASSISTments. Specifically, in Feng and colleagues' study (2021), only 49% of their participating students completed the problem set before the COVID-19 restrictions began in March 2020, and the completion rate decreased to 28% after March 2020. We conducted a chi-square test comparing the completion rate across the six conditions, and the differences between conditions were not significant, $\chi2(5, N = 454) = 4.23$, p=.52.This research was approved by the Institutional

Review Board at a university in the Northeastern United States. This research involved typical educational practices and did not require parental consent or student assent.

Procedure

This study was conducted within ASSISTments, an online tutoring system (Heffernan & Heffernan, 2014; www.assistments.org). ASSISTments, teachers can assign problem sets to students, and students can receive hints and correctness feedback during problem-solving. ASSISTments includes the technical infrastructure for conducting randomized controlled trials and is actively used by 500,000 students and 20,000 teachers around the world (ASSISTments, 2021). The platform thus provides a convenient and ecologically valid context for researchers to study student learning and problem-solving in an online environment. We utilized ASSISTments as an online study platform in which students received the pretest, worked examples with paired practice problems, and the posttest in one problem set. The problem set was designed to be completed online in one 60-minute session. Teachers assigned the online problem set for their students to complete in mathematics classrooms during instructional periods, and students worked individually at their own pace using a device. If additional time was needed, students completed the assignment as homework or in a subsequent class period at the discretion of the teacher. As students opened the problem set, they were randomly assigned to one of six worked example conditions. All students first completed an eight-item pretest on algebraic equation solving. Next, they completed six problem pairs, each consisting of one worked example and one practice problem. The six pairs of worked examples and practice problems were presented in the same order across all conditions. Within each pair of worked examples and practice problems, students first studied the worked example for as long as they needed, then entered the answer of the worked example on the screen (e.g., 3 in Figure 1, left). We asked students to enter the answer of each worked example to ensure that they looked at the worked example prior to solving the practice problem. Next, students solved a paired practice problem mirroring the structure of the worked example without the worked example in view (Figure 1, right). All six-practice problems were identical across conditions (Table A1). Students then finished the problem set by completing a posttest mirroring the pretest. Students did not receive any accuracy feedback while completing the problem set.

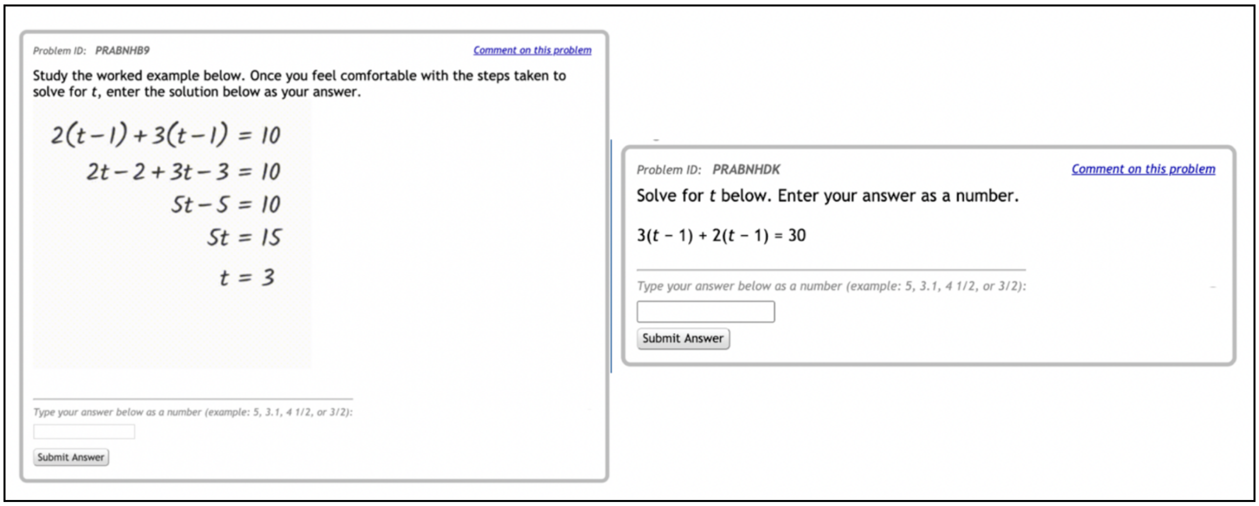

Figure 1. *Left:* Example of a static concise worked example as seen by a participant in the online tutoring system. *Right:* The following paired problem to be completed for practice.

Pretest and Posttest

The eight-item pretest was constructed with six problems adapted from two open-source curricula, Engage New York (2014) and UtahMath Project (2016), and two problems designed by the authors (see Table B1 for all items). We selected and adapted six algebra equation-solving problems, then designed the remaining two problems following the structure of the worked examples. Of the eight problems, four had similar equation structures as the worked examples (items 1, 4,7, and 8) and the remaining four did not (items 2, 3, 5, and 6). This design ensured that the pretest aligned with the content presented in our worked example study yet was representative of the problems students might encounter in classrooms. The eight-item posttest mirroring the pretest was then created by substituting numbers of similar magnitudes and maintaining the equation structures in the pre-test problems. Each item was scored as correct (1) or incorrect (0), and the reliability of these eight items was KR-20=0.86 at the pretest and KR-20=0.89 at posttest. The percent correct on pretest and posttest were included as the covariate and dependent variable, respectively, in the primary analyses.

Experimental Conditions

We designed six conditions varying in how extended and dynamic the worked examples were presented. The worked examples were adapted from Rittle-Johnson and Star (2007), a project aimed to improve middle-school students' equation-solving performance. The starting equation of each worked example was identical for all students, and the presentation of the derivation steps varied across conditions. The first four conditions were based on a 2 (static vs. sequential)2 (concise vs. extended) design in which either the worked examples were presented fully in a static image, or each line of the worked examples was presented sequentially over time. Within static and sequential conditions, the worked examples showed either only the major derivation steps (concise) or all of the steps (extended; See Figure 2). Different from the first four conditions, the remaining two conditions involved dynamic presentations of worked examples. In both dynamic conditions, students saw all derivation steps for each worked example as well as the animation of the equation transformation processes. The two conditions varied in whether the history of the derivation remained on the screen or not (Figure 3). We describe each condition in detail below.

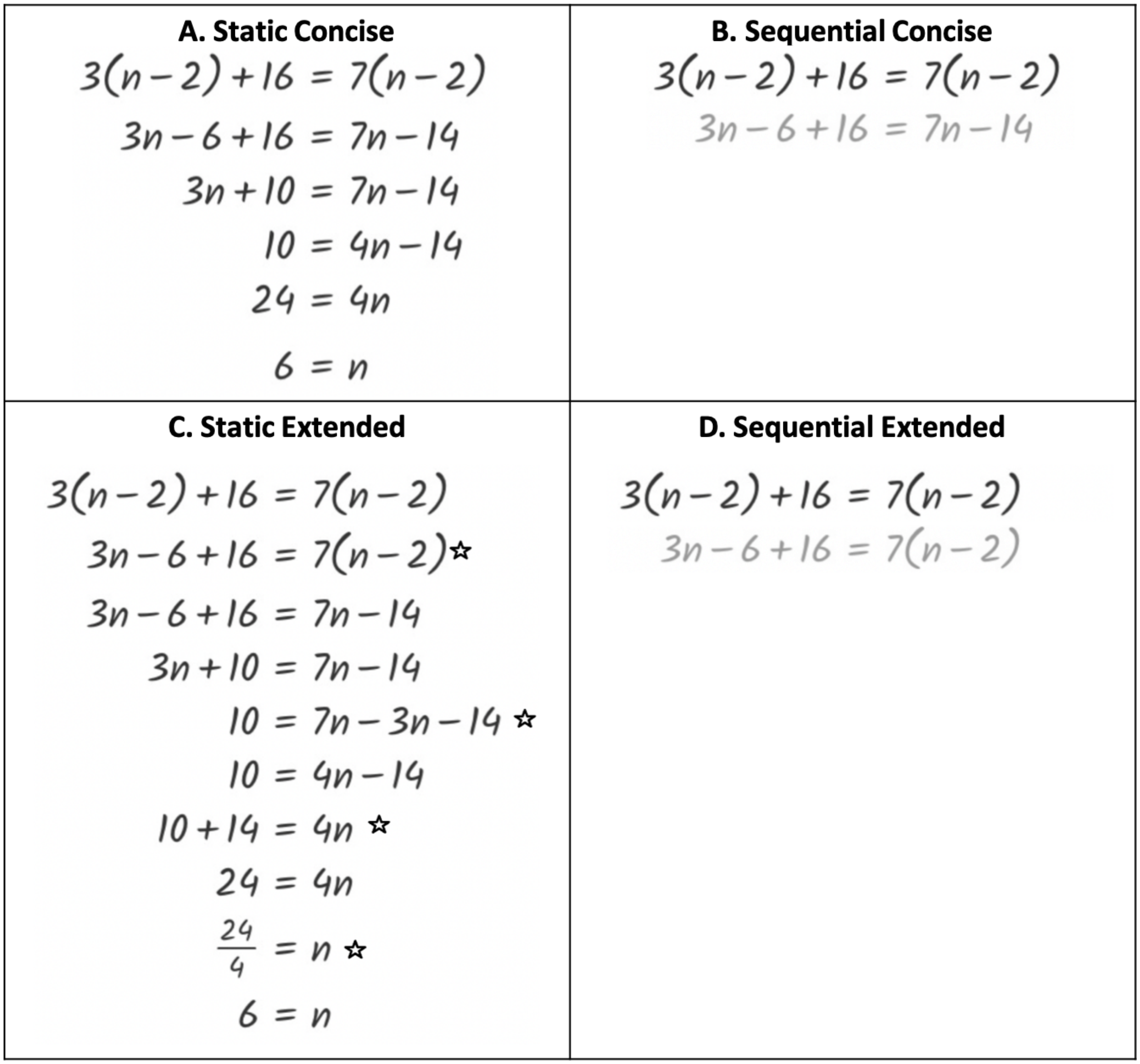

Figure 2. A worked example in the (A) static concise, (B) sequential concise, (C) static extended, and (D) sequential extended condition. In the sequential conditions, each step of the derivation is revealed over time. The stars in panel C indicate the additional derivation steps displayed in the extended, but not concise, conditions.

Static Concise

A static concise worked example was presented as a static image that displayed the major steps in the derivation (Figure 2a). The worked examples in this condition were identical to those used by

Rittle-Johnson and Star (2007), except for the font in which the worked examples were presented. Rittle-Johnson and Star presented the worked examples in Times New Roman, whereas we presented the worked example in Kalam (the font type used in GM). We made this modification to match the font type of the worked examples across conditions. The static concise presentation of worked examples aligned with those used in textbooks (Engage New York, 2014) and other research studies (e.g., Sweller & Cooper, 1985).

Static Extended

A static extended worked example was presented as a static image that displayed the steps in the derivation (Figure 2c). Similar to the static concise worked example, each static extended worked example presented the derivation steps simultaneously in one static image. Unlike the static concise worked example, the static extended worked examples explicitly displayed each and every step of the derivation, extending beyond the scope of the concise conditions.

Sequential Concise

A sequential concise worked example was presented as a GIF video that displayed the major steps in the derivation one step at a time. The steps of the derivation presented in the sequential concise condition were identical to those in the static concise condition, but they appeared on the screen one line at a time in two- to three-second intervals, creating a history of the derivation over time. When the last step of the worked example (e.g., 6=n) was presented, the complete derivation remained on screen for 5–7 s, allowing time for students to view the completed example. After this, the video automatically repeated from the beginning so that students could watch the video as many times as they wished.

Sequential Extended

A sequential extended worked example was presented as a GIF video that displayed all the steps in the derivation one step at a time. Each Sequential extended worked example was identical to that in the static extended condition, but the steps were added on the screen one at a time in two- to three-second intervals. Similar to the worked examples in the sequential concise condition, the complete derivation remained on-screen for 5–7 s, then the video automatically repeated from the beginning.

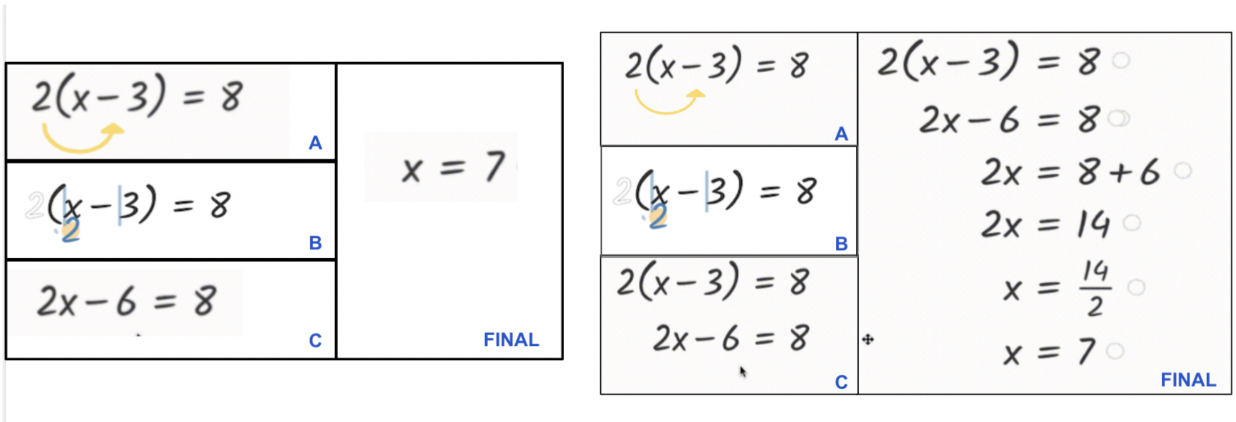

Figure 3. *Left*: Dynamic no history condition in which all transformations occur on one line. *Right*: Dynamic history condition in which the result of each transformation is added as a new line creating a sequential derivation of the worked example.

Note: Panels in both figures illustrate (A) the intended action of dragging 2 inside the parentheses, (B) the fluid transformation of distributing 2 over x and -3, (C) the result of the transformation, and (Final) the end result with the solution of the worked example.

Dynamic History

A dynamic history worked example was presented as a GIF video that displayed the process of solving an equation using the GM tool. For example, in 2(x3)=8, students watched as the 2 was dragged into the parentheses, and the equation was transformed into 2x6=8. The result of the transformation (e.g., 2x6=8) was then added as a new line in the derivation, and the next action was made on this new line of the derivation (Figure 3 Right). As each line of the derivation was added, a history of the equation-solving process was created. The complete derivations were identical to those in the two extended conditions (static extended and sequential extended), but actions and fluid transformations between each step of the derivation were demonstrated in the video. As the video reached the end of the equation-solving process, the complete derivation remained on-screen for 5–7 s, then the video automatically repeated from the beginning.

Dynamic No History

Similar to the dynamic history worked examples, the dynamic no history worked examples were presented as a GIF video that displayed each step of the derivation that was created using the GM tool. However, instead of displaying the history of the derivation by adding a new line after each action, all the actions were made on the initial equation. Students watched the initial equation (e.g., 2(x3)=8)being transformed into the answer (e.g.,x=7) over time in one line without the step-by-step history of the complete derivation. As the video reached the end of the equation-solving process, the solution remained on screen for 5–7 s, then the video automatically repeated from the beginning.FIGURE 3 Left: Dynamic no history condition in which all transformations occur on one line. Right: Dynamic history condition in which the result of each transformation is added as a new line creating a sequential derivation of the worked example. Panels in both figures illustrate(a) the intended action of dragging 2 inside the parentheses, (b) the fluid transformation of distributing 2 overhand 3, (c) the result of the transformation, and (final) the end result with the solution of the worked example.

Approach To Analysis

Prior to testing our primary hypotheses, we first reported descriptive statistics of pretest and posttest scores by worked example conditions. We also conducted a paired-sample t-test to examine overall learning from worked examples regardless of the presentation conditions. Next, we conducted a one-way ANOVA to examine whether students' pretest scores were comparable across conditions and to inform our primary analyses. To test our hypotheses, we first conducted a one-way ANCOVA comparing students' posttest scores across the six worked example conditions while controlling for their pretest scores. The posthoc power analysis revealed that the sample size afforded 90% power to detect a moderate to large effect of worked example format ($f \geq 0.27$)in the current study. The conventional cut-offs for small, medium, and large effects are 0.10, 0.25, and 0.40, respectively (Cohen, 1992). Next, to compare the effects of concise vs. extended, as well as static vs. sequential formats, and to test the potential interaction between these two factors, we conducted a 2 (concise vs. extended)2(static vs. sequential) ANCOVA controlling for pretest scores. This ANCOVA did not include either dynamic condition because they did not align with the concise vs. extended, or static vs. sequential, formats. Instead, to investigate how the extensiveness in dynamic worked examples may impact learning, we conducted a one-way ANCOVA comparing students' posttest scores between the dynamic history and dynamic no history conditions while controlling for pretest score. Finally, informed by the findings on the extensiveness in worked examples, we collapsed across concise and extended as well as history and no history conditions to investigate how the level of dynamicness impacted student learning from worked examples. We conducted a one-way ANCOVA comparing students' posttest scores after viewing worked examples in static (concise and extended), sequential (concise and extended), and dynamic (history and no history) formats while controlling for pretest scores. Collapsing across conditions allowed us to specifically examine the effect of the level of dynamicness in the worked example above and beyond the effect of extensiveness. To further explore the effects of worked example formats and to extend beyond the aforementioned frequentist analysis, we included Bayesian statistics for all analyses. The Bayesian approach allows us to go beyond the null results in frequentist analyses, and we are able to detect evidence in favor of the null hypothesis by comparing the strength and likelihood of both the alternative and null hypothesis models. In this way, we are able to determine whether the alternative or null hypothesis is more likely (Lakens et al., 2020). All analyses were conducted with JASP (JASP

Team, 2020; Wagenmakers et al., 2018). We used the default, non-informative prior specifications in JASP for all Bayesian analyses as recommended by Faulkenberry et al. (2020). The default specification uses a JZS (multivariate Cauchy) prior to the effect scales with a default scale of 0.5. Per Goss-Sampson et al. (2020), we used the scale of strength of evidence to interpret the Bayes factor (BF10). A value of 0–1 provides no evidence for either the alternative or the null hypothesis. The cutoffs of anecdotal, moderate, strong, very strong, and decisive evidence for the alternative hypothesis are 3, 10, 30, 100, and over 100, respectively. Similarly, the cutoffs of anecdotal, moderate, strong, very strong, and decisive evidence for the null hypothesis are 0.33, 0.10, 0.033, 0.01, and less than 0.01, respectively.

Results

Preliminary Analysis

The descriptive statistics revealed that the pretest and posttest scores were not subject to ceiling or floor effects (Table 1). On average, students scored 41% (SD=34%) on the pretest and 48% (SD=37%) on the posttest. The scores were widely distributed, as indicated by the standard deviation, suggesting that the pretest and posttest captured the variability in the students' equation-solving performance within the sample. A paired-sample t-test revealed that, regardless of conditions, students significantly improved from pretest to posttest, $t(229)=3.69, p<.01, d=0.24$. In addition, a Bayesian paired sample t-test revealed a Bayes factor of BF10=50.99, providing very strong evidence that students scored higher on the posttest compared to pretest. Prior To conducting our primary analyses, we first examined whether students' pretest scores were comparable across the six conditions. A one-way ANOVA revealed that students' pretest scores did significantly differ by condition, $F(5,224)=2.91, p=.015$. Further, the data provided anecdotal evidence for the differences in pretest scores by condition, BF10=1.62. The posthoc pairwise comparisons with Bonferroni correction revealed that the difference between static concise and dynamic history conditions were significant,$p=.02$. The Remaining pairwise comparisons were not significant, $ps>.10$. Due to the differences in pretest scores across conditions, we controlled for pretest scores to test the effect of work example conditions on the posttest performance in the following analyses.

Table 1. Means and standard deviations of pretest and posttest scores by condition

		Pretest		Posttest	
Condition	*N*	*M*	*SD*	*M*	*SD*
Static Concise	42	0.307	0.313	0.440	0.333
Static Extended	48	0.417	0.318	0.474	0.376
Sequential Concise	33	0.352	0.354	0.402	0.395
Sequential Extended	38	0.366	0.314	0.431	0.370
Dynamic History	33	0.553	0.337	0.583	0.342
Dynamic No History	36	0.503	0.376	0.542	0.380

Condition Effects

A one-way ANCOVA comparing students' posttest scores by the six worked example conditions while controlling for their pretest scores revealed that there was no main effect of condition, $F(5,223)=.38, p=.86. \eta2=0.004$. Students' posttest performance did not significantly differ by worked example conditions (Figure 4). Further, a Bayesian ANCOVA revealed strong evidence that there was no effect of condition on posttest scores, BF10=0.076. As expected, students' pretest score was a significant and positive covariate of their posttest score, $F(1,223)=234.56, p<.01. \eta2=0.51$. Bayesian analysis confirmed this result with decisive evidence that pretest score was associated with posttest score, (BF10>100).

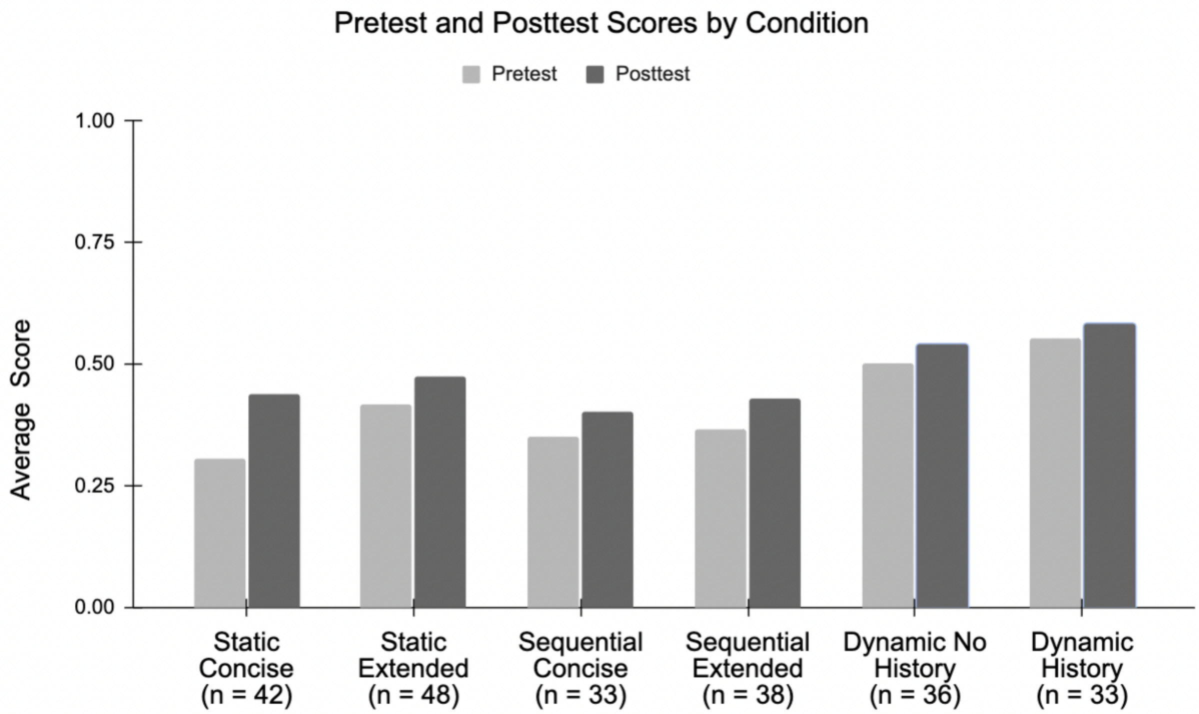

Figure 4. Pretest and posttest scores by worked example presentation conditions.

Extensiveness: concise versus extended and history versus no history

Next, a 2 (extensiveness: concise vs. extended)2 (dynamicness: static vs. sequential) ANCOVA controlling for pretest score revealed that there was no main effect of extensiveness, $F(1, 156)=0.148, p=0.701, \eta2<0.001$. A Bayesian ANCOVA revealed moderate evidence that extensiveness had no effect on posttest scores, BF10=0.196. There was no main effect of dynamicness, $F(1, 156)=0.831, p=.363, \eta2=0.003$, with moderate evidence supporting this null finding, BF10=0.216. There was also no interaction effect,$F(1, 156)=.668, p=.415, \eta2=0.002$, with very strong evidence supporting thisnull finding,BF10=0.01. As expected, students' pretest score was a significant and positive covariate of their posttest score, $F(1,156)=135.216, p<0.01, \eta2=0.462$, which was confirmed by the Bayes factor indicating decisive evidence, BF10>100. We also conducted a one-way ANCOVA comparing students' posttest scores in dynamic no history and dynamic history conditions while controlling for their pretest scores. The ANCOVA revealed that the effect of condition was not significant, $F(1, 66)=0.001, p=.97, \eta 2<0.01$. Students in the dynamic no history condition did not outperform students in the dynamic history condition. The Bayes factor indicated moderate evidence for this null finding, BF10=0.273. As expected, students' pretest score was significant and positive covariate of their posttest score, $F(1,66)=112.26, p<.01, \eta 2<0.63$, which was confirmed by the Bayes factor indicating decisive evidence, BF10>100.

Dynamicness: static versus sequential versus dynamic

Finally, a one-way ANCOVA comparing students' posttest scores in static, sequential, and dynamic presentation formats while controlling for their pretest scores revealed that there was no main effect of presentation format, $F(2,226)=.43, p=.65, \eta 2=0.002$. Students' posttest performance did not significantly differ based on how dynamic the worked examples were presented (Figure 5). A Bayesian ANCOVA revealed anecdotal evidence (BF10=0.607) in favor of this null finding. As expected, students' pretest score was a significant and positive covariate of their posttest score, $F(1,226)=236.64, p<.01, \eta 2=0.51$, which was confirmed by the Bayes factor indicating decisive evidence for this finding, BF10>100.

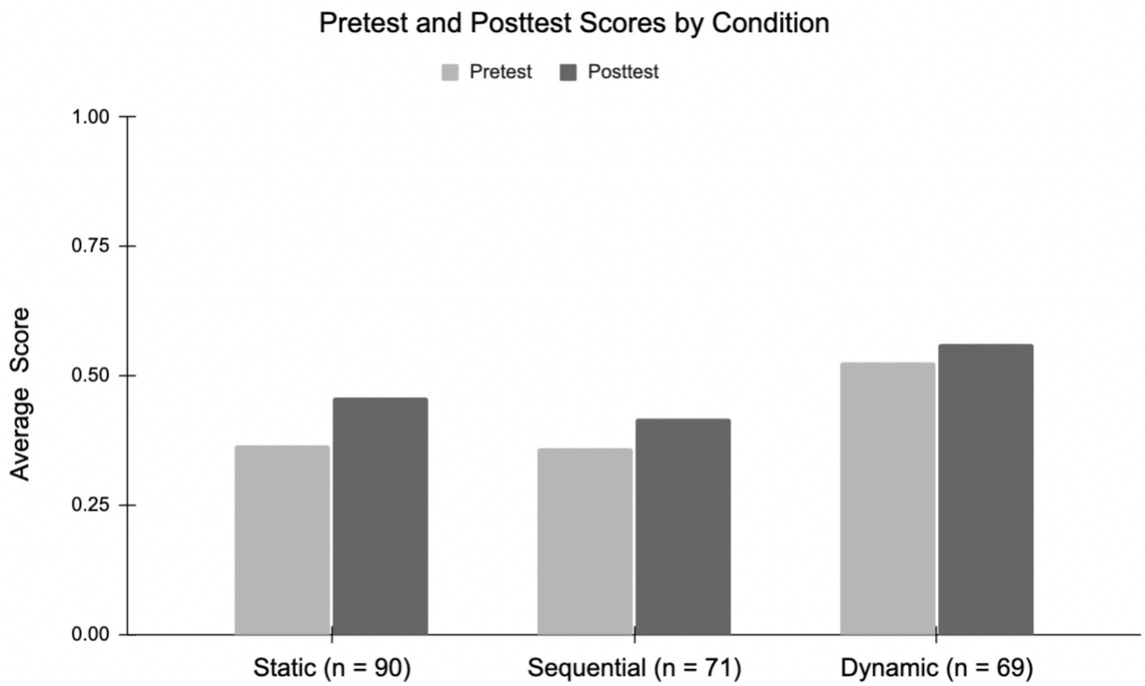

Figure 5. Pretest and posttest scores by static, sequential, and dynamic conditions.

Discussion

In this study, we set out to identify which presentation of worked examples was most beneficial for students to view and to test how different presentation features impact learning from worked examples in an online platform. We found that on average, students improved their algebraic equation-solving performance from pretest to posttest after completing a brief activity with worked examples and paired practice problems. Extending the literature on worked examples, we found that, after controlling for pretest scores, students' posttest scores did not significantly differ between (a) the six worked example conditions, (b) the concise vs. extended or history vs. no history presentation formats, or (c) the static vs. sequential vs. dynamic presentation formats. These findings were further strengthened by the Bayesian analysis providing strong evidence that (a) students' posttest scores did not differ across six conditions, and moderate evidence that (b) the extensiveness and (c) the level of dynamicness did not differentially impact students' posttest scores. Students across six conditions improved their performance from pretest to posttest, suggesting that the worked examples, regardless of their formats, were effective. These results contribute findings to cognitive load theory and perceptual learning theory that may guide future designs of worked examples. We discuss these findings and their implications in detail below.

Worked Example Effect

We found that students, averaging across six conditions, experienced learning gains from pretest to posttest, which aligns with prior research on the worked example effect (Booth et al., 2013; Carroll, 1994; Foster et al., 2018). Given that the worked example effect is well substantiated in the literature, the current experiment explored the differential effects of worked example presentations with one brief activity that included an immediate pretest and posttest. Our effect size for the pretest vs. posttest comparison across six conditions (d=0.24) was comparable to that of a prior study with Algebra I students in an online intervention study (d=0.19; Boothet al., 2013), aligning with prior literature on the worked example effect. Together, our finding suggests that the learning gains may be attributed to students' participation in the worked example activity regardless of the worked example formats. Given that the results show ubiquitous learning gains without reliable differences by condition and strong evidence suggesting the lack of condition effect, it was possible that different presentations of the same worked example may be equally beneficial for student learning. This finding aligns with prior research demonstrating that students benefit from studying different worked example presentations (Reed et al., 2013). One potential implication of this finding is that teachers and content developers may have the flexibility to utilize various technologies and formats, including dynamic educational technologies, to create different presentations of worked examples for online settings. This flexibility may also allow students more autonomy in their choice of worked example presentations and benefit from the additional level of choice during online practice. Prior work has demonstrated that students who were allowed to choose their feedback format (text or video) after mathematics problem-solving in an online problem set outperform their peers who were randomly assigned to a feedback format (Ostrow & Heffernan, 2015). Similar to Ostrow and Heffernan's finding that feedback formats, when randomly assigned, did not impact students' learning, we found that worked example formats did not impact student learning of algebraic equation solving. A future direction is to conceptually replicate this research by providing students with choices of worked example formats and examining the impacts of choice on student learning.

Extensiveness and dynamic presentations of worked examples

We hypothesized that concise worked examples may be more beneficial for student learning compared to extended worked examples. However, when comparing worked examples that presented the concise derivation vs. complete derivation of an algebra problem, we did not find differences in students' posttest scores and there was moderate evidence in support of this null finding. We also did not find an effect of showing vs. not showing the history of dynamics worked examples on students' posttest scores and there was moderate evidence in support of this finding. The lack of an effect combined with the moderate evidence of the null findings on concise vs. extended and history vs. no history worked examples suggest that perhaps the extensiveness of a worked example may not impact student learning. Alternatively, the extensiveness of a worked example may differentially impact student learning at different stages. Pollock et al. (2002) found that novice learners in a high school industrial skills course benefited from exposure to worked examples with extensive details before studying worked examples without extensive details. Perhaps, novice learners may benefit from first studying the extended worked examples, then gradually transitioning to concise worked examples. However, among our sample of Algebra I students who were still learning algebraic equation-solving, we did not find that students benefited more from the extended worked examples compared to the concise worked examples. Because our sample was algebra learners and the number of students within each condition was relatively small, we did not further explore the effect of concise vs. extended worked examples on students with varying levels of prior knowledge. Future Studies should recruit a larger sample to examine the effect of conciseness. extended worked examples among students at different phases of algebra learning. If the later findings on algebra learning replicate Pollock and colleagues' work, teachers and content designers may consider varying the extensiveness of the worked examples based on students' knowledge level in order to better support learning through individualized practices. Based on perceptual learning theory (Gibson, 1969), we initially hypothesized that worked examples with dynamic presentation may direct students' attention to important pieces of notation and support learning beyond viewing static or sequential worked examples. Contrary to our hypothesis, we found that there were no significant differences between worked examples presented in static, sequential, or dynamic formats and that there was anecdotal evidence in support of no differences between conditions. One possible interpretation is that these nuanced variations of worked example formats may be equally effective for student learning. If so, students, teachers, and content designers may have the flexibility to choose their preferred worked example when teaching or learning. Alternatively, different factors may contribute to the seemingly comparable effects of worked example formats. In particular, based on anecdotal feedback from participating teachers, videos of the dynamic worked examples might be too fast for students to follow the derivation steps. Perhaps, dynamic worked examples do direct students' attention to the important problem-solving procedures; however, without a pause button to control the speed of the video, the dynamics worked examples may inadvertently increase students' cognitive load, preventing the dynamic, fluid transformations from being more helpful for learning beyond viewing static examples. Another explanation may be that students are used to static worked examples in their textbooks and curricular materials, and the novelty of the videos may have decreased the initial impact of the dynamic worked examples. If this is the case, providing students with more experience viewing the dynamic worked examples by increasing the number of worked examples and the learning sessions in the study should improve student learning above and beyond viewing statics worked examples. With the anecdotal evidence for the null finding, the current result is inconclusive. With a larger sample of students, future studies should further investigate the potential affordances of dynamic worked examples, and how to maximize their effectiveness for student learning.

Limitations and Future Directions

Several limitations warrant mentioning. First, approximately half of the students enrolled in the study did not complete the pretest and were excluded from the analyses. The majority (69%) of these students excluded from the analyses dropped out of the study prior to viewing the worked examples, suggesting that the attrition may not be associated with the experimental conditions. Even though we asked teachers to dedicate instructional time for students to complete the study, teachers were likely to assign the study problem set as a supplemental practice or ungraded homework assignment withinASSISTments, providing little motivation for students to complete the entire problem set. Further, this study was conducted in schools during the COVID-19 pandemic where there was a lot of disruption to typical everyday practice; therefore, the disruption related to COVID-19 may also contribute to the high attrition rate. Given that the completion rate of our study was comparable to that of a prior study usingASSISTments (e.g., Feng et al., 2021), we posit that the relatively low completion rate might not be specific to our study but more general to the platform. Next, after accounting for attrition, the sample size within each worked example condition was relatively small, and the experimental manipulation on the worked example format was modest, with overlapping manipulations to each condition. It also was possible that some idiosyncratic aspects of the worked example formats, such as the speed of the videos, or students' individual characteristics, such as their learning phases and preferences of worked examples, contributed to how much students learned from the worked examples in the current study. Although a power analysis suggested that we had adequate power to detect a moderate to large effect of the worked example formats, we might still be underpowered to detect the nuanced effects from a brief worked example session. Further, the worked examples in the current study only focused on exemplifying the equation-solving process within algebra. Therefore, the findings cannot be generalized to other types of worked examples that focused on learning and strategies, or other non-algorithmic domains, such as argumentation (e.g., Schworm & Renkl, 2007) and medical diagnostics (e.g., Stark et al., 2011). Future studies should investigate the impact of various types of worked examples, content areas, as well as students' prior knowledge, choice, feedback, and perceived helpfulness of the worked examples to further investigate how these factors together impact student learning from worked examples. Finally, our findings suggest that the extensiveness or dynamic-ness of worked examples may not significantly impact students' algebra learning. However, a main limitation is that this study was conducted as a brief online intervention within the context of algebra worked examples. The current study provides a starting point for future work to further investigate how these factors impact student learning from worked examples. Future studies should replicate current findings with a larger sample, a longer-term intervention over multiple class periods, and delayed posttests, comparable to related research on the effects of worked examples in online settings(e.g., Booth et al., 2013; McLaren et al., 2016; Reed et al., 2013). Doing so will provide stronger and more conclusive evidence of how the extensiveness or dynamicness of worked examples may impact students' algebra learning. Future work should also examine other outcomes, such as learning efficiency, in addition to posttest performance, as a result of participating in worked example practice (McLaren et al., 2016). Prior Studies have found that students achieved the same level of performance in less amount of time when viewing worked examples compared to solving practice problems (Salden et al., 2010). Although we did not find an effect of worked example formats on posttest performance, there may be an effect of formats on learning efficiency such that some presentations may require less study time than others to be beneficial. Identifying the unique affordances of different worked example presentations will further inform the design of worked examples in online learning environments and better support student learning. Future work should also examine the mechanisms through which these worked example formats impact learning. Another future direction is to measure students' cognitive load or eye gaze in order to further investigate the relations between cognitive load theory, perceptual learning theory, and the worked example effect.

Conclusion

We found that, on average, students improved from pretest to posttest after completing a problem set with one of six different presentations of worked examples, suggesting that regardless of work example format, students improved their algebra performance through this online activity. In addition, we found strong evidence for the result that student learning did not significantly differ between experimental conditions, leading us to conclude that worked examples, regardless of their formats, may be effective learning tools. These results have implications for designing worked examples based on principles of cognitive load theory and perceptual learning theory, as both theories have informed teaching and learning. It seems that including more details in worked examples may not decrease student performance compared to viewing worked examples with less details. Further, including perceptual features to guide students' attention in worked examples may not lead to additional gains beyond the traditional static worked examples. These results have implications for classrooms and the design of online worked examples in tutoring systems. Specifically, teachers and content creators may be able to design different presentations of worked examples that will still be effective for learning.

Acknowledgments

We thank the ASSISTments Foundation and Worcester Polytechnic Institute for hosting the www.etrialstestbed.org that made this study possible and that is funded by two National Science Foundation grants(1724889 & 1931523) and Schmidt Futures. The research and development reported here was also supported by the Institute of EducationSciences, U.S. Department of Education through the Small BusinessInnovation Research (SBIR) program contracts 91990019C0034 and 91990018C0032 to Graspable Inc. The opinions expressed are those of the authors and do not represent views of the National Science Foundation, the Institute of Education Sciences or the U.S. Department Of Education. We thank Anthony Botelho, Cindy Trac, Hailey Anderson, and members of the Math Abstraction Play Learning and EmbodimentLab for their work on this project, and the participating teachers and students for their support with this study.

Data Availability Statement

The final dataset for the current study is available on the Open Science Framework at https://osf.io/uv48t/?view_only=b23d407d698f423b9d037fec646ca98b.

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Appendix A. Algebraic equations used in worked examples across all conditions and the paired problem shown after each worked example.

Worked Example (concise format)	Paired Practice Problem
$2(x - 3) = 8$ $2x - 6 = 8$ $2x = 14$ $x = 7$	$-3(y - 4) = 18$ $-3y + 12 = 18$ $-3y = 6$ $y = -2$
$2(t - 1) + 3(t - 1) = 10$ $2t - 2 + 3t - 3 = 10$ $5t - 5 = 10$ $5t = 15$ $t = 5$	$3(t - 1) + 3(t - 1) = 30$ $3t - 3 + 3t - 3 = 30$ $6t - 6 = 30$ $6t = 36$ $t = 6$
$5(y + 1) = 3(y + 1) + 8$ $5y + 5 = 3y + 3 + 8$ $5y + 5 = 3y + 11$ $2y + 5 = 11$ $2y = 6$ $y = 3$	$5(m + 4) = 2(m + 4) + 15$ $5m +20 = 2m + 8 + 15$ $5m + 20 = 2m + 23$ $3m + 20 = 23$ $3m = 3$ $m = 1$
$3(n - 2) + 16 = 7(n - 2)$ $3n - 6 + 16 = 7n - 14$ $3n + 10 = 7n - 14$ $10 = 4n - 14$ $24 = 4n$ $6 = n$	$3(n - 2) + 12 = 6(n - 2)$ $3\mathrm{n} - 6 + 12 = 6n - 12$ $3n + 6 = 6n - 12$ $6 = 3n - 12$ $18 = 3n$ $6 = n$
$9 = 5(m + 2) + 4(m + 2)$ $9 = 5m + 10 + 4m + 8$ $9 = 9m + 18$ $-9 = 9m$ $-1 = m$	$9 = 3(y + 5) + 6(y +5)$ $9 = 3y + 15 + 6y + 30$ $9 = 9y + 45$ $-36 = 9y$ $-4 = y$
$3(h - 2) + 5(h - 2) = 24$ $3h - 6 + 5h -10 = 24$ $8\mathrm{h} - 16 = 24$ $8h = 40$ $h = 5$	$6(w - 4) + 7(w - 4) = 26$ $6w - 24 + 7w - 28 = 26$ $13w - 52 = 26$ $13w = 78$ $w = 6$

Note: The worked example derivations are those used by Rittle-Johnson and Star (2007) and do not include the extra steps included in the derivations for the extended worked example conditions.

Appendix B. Pretest and Posttest Items.

Pretest Items	Source	Posttest Items	Open Source
$8(2x + 9) = 56$	Engage NY	$11(x + 10) = 132$	Engage NY
$-(x - 5) + 2 - x = 3$	Project Utah	$-(4x - 10) + 4 - 4x = 6$	--
$5 - 4(2b - 5) + 3b = 15$	Project Utah	$30 - 4(b - 5) + 1b = 20$	--
$10 = 3(x - 2) - 2(5x - 1)$	Project Utah	$20 = 3(2x - 2) - 2(5x - 1)$	--
$3(2x - 14) + x = 15 - (-9x - 5)$	Engage NY	$6\ (4x - 28) + 2x = 30 - (-18x - 10)$	--
$-4x - 2(8x + 1) = -(-2x - 10)$	Engage NY	$-6x - 4(3x + 2) = - (-1x - 2)$	--
$5(y - 12) = 3(y - 12) + 20$	Authors	$2(y - 4) = (y - 4) + 6$	--
$3(h + 2) + 4(h + 2) = 35$	Authors	$2(h + 1) + 4(h + 1) = 12$	--

Chapter 3. Can Mental Rotation Predict Performance in an Online Geometry Assignment?

This chapter presents the pre-print version of the following manuscript:

Smith, H., Ramey, K., Heffernan, N., Uttal, D., (June 2022) Can mental rotation predict performance in an online geometry assignment? Proceedings of the 15th International Conference of the Learning Sciences

Abstract

While mental rotation knowledge has been linked to math performance, specifically in geometry, it is unclear when, why, and how mental rotation affects achievement. We extend prior research by examining the relationship between mental rotation skill and students' performance in two online geometry assignments covering different topics (e.g., translations, rotations) and presented in two different ways to prime problem-solving strategies (e.g., analytic, visuospatial). Within each problem set, students completed four mental rotation problems, then an online problem set on either translations or rotations. The results indicated that: (1) mental rotation skill predicted assignment mastery speed regardless of topic; (2) problem presentation did not affect mastery speeds; (3) there was no interaction between mental rotation skill and problem presentation on mastery speed. These results indicate that mental rotation skill may be more important in solving geometry problems than problem presentation and which strategies students may use.

Introduction

It is well documented that spatial skills predict math achievement (e.g., Geer et al., 2019; Tosto et al., 2014; Uttal et al., 2012; Verdine et al., 2017; Wai et al., 2009), among both elementary and middle school students (Li & Geary, 2013) and, more specifically, in geometry (Delgado & Prieto, 2004; Pittalis & Christou, 2010; Weckbacher & Okamoto, 2014). For example, increased spatial skills led to about 5%–14% gains in math achievement among 6 - 10-year-old children (Gilligan et al., 2019), and similar gains have been found among first and fifth-grade students (Li & Geary, 2013). Also, spatial skills (which were measured by students' performance on 2-dimensional figure tasks) predicted high achievement on state-wide exams after considering other factors such as socioeconomic status (Carr et al., 2018). However, arguments still abound as to when, why, and how spatial skills affect students' math achievements and later success in STEM disciplines (e.g., Wai et al., 2009).

A significant body of research also suggests that spatial skills are malleable (Uttal & Cohen., 2012), however, a question remains in how transferable skills are from one domain to another or even within one domain on different topics. In their analysis of over 200 studies on the malleability of spatial skills, Uttal and Cohen (2012) reaffirmed the malleability of spatial skills, but their findings regarding the transferability of the learned skill were inconclusive. For example, whereas some have found that spatial skills cannot be transferred (e.g., National Research Council, 2006; Sims & Mayer, 2002; Schmidt & Bjork, 1992; Terlecki et al., 2008; Wright et al., 2008), others have found evidence that they can be transferred (e.g., Lohman & Nichols, 1990). Thus, the transferability of spatial skills may not be all-encompassing but only apply to similar problems (Uttal et al., 2013). Not all problems involve the same steps or cognitive processes to solve. For example, in geometry, some problems, like rotating figures on a coordinate plane, might map better onto certain spatial skills, like mental rotation. Typical psychometric assessments might only test one specific type of spatial skill (e.g., mental rotation), so it is unclear whether mental rotation performance only impacts performance on geometry problems involving rotation or whether it would impact performance on other types of problems as well (e.g., translations; moving across a coordinate grid in a given direction). Therefore, here, we explore whether spatial skills are predictive of success across different topics within geometry (e.g., rotations and translations) and whether their impact extends beyond geometry rotation problems.

In addition, studies have been conducted to explore different strategies students use to solve problems involving mental rotation skill (Kozhevnikov et al., 2002a; Schwartz & Black, 1996; Stieff, 2007). For example, in chemistry, students have been shown to use both visuospatial strategies to solve problems, therefore relying on their mental rotation skill, as well as analytic strategies which rely on analytic shortcuts or heuristics instead of the spatial information presented (Schwartz & Black, 1996; Stieff, 2007). It has been hypothesized that other factors beyond spatial skills may impact success in STEM disciplines, such as representational competence (Stieff, 2011) and domain-specific problem-solving strategies (Stieff, 2007; Stieff et al., 2014). Further, it has been shown that the way a problem is presented to students can prime them to solve the problem with a particular strategy and that using multiple problem representations has led to better performance (e.g., Ainsworth, 1999, 2006). For example, algebra students who were presented with word problems with different representations, including verbal and diagrams, solved the problems using different strategies, including algebra and diagrams. Most importantly, learners who used multiple representations and strategies had higher performance (Ainsworth, 1999).

Other studies have shown individual preferences for particular problem-solving strategies, visuospatial or verbal/analytic (Kozhevnikov et al., 2002a; Stieff, 2007). For example, Kozhevnikov et al. (2002a) identified learners who tended to prefer using visual or spatial imagery to solve problems as visualizers those who did not have a preference for visual or spatial strategies as non-visualizers.

Problems can also be presented to learners in ways that elicit different strategies: analytic or visuospatial. In addition, learners' problem-solving strategies may interact with their spatial ability, where different problems may require the use of more spatial strategies than others (Kozhevnikov et al., 2002b), or representation type (e.g. Keehner et al., 2004) to influence performance. Moreover, prior work has shown that the use of different strategies, such as analytic as opposed to visuospatial, may mitigate the impact of individual differences in spatial skills (Stieff, 2007). Much work has been conducted in chemistry (Stieff, 2007), however, it is still unclear how spatial skills may influence different problem-solving strategies in geometry, and how the representation of the problem may influence the use of different strategies and ultimately impact performance.

Additionally, while many studies have explored the impact of spatial skills on math performance, there have been few studies that investigate the relationship between spatial skills and math performance in online tutoring systems. It has been shown that spatial skills are related to the types of gestures learners use when solving problems (Göksun et al., 2013) and that gestures can help learners solve geometry problems in physical environments (Walkington et al., 2014). Online environments offer a unique space to solve problems, which may limit the use of outside resources such as gestures. It is important to investigate the impact of spatial skills in different environments, as they allow different affordances to students such as providing hints as well as the different tactile experiences of problem-solving with pen and paper vs in a physical environment vs on a computer screen. Therefore, students' spatial skills may predict behaviors in an online tutoring system differently than has been reported previously.

The Present Study

In the current study, we explored whether mental rotation skills are predictive of performance above and beyond problem presentation and problem-solving strategies, or whether there are other factors beyond mental rotation skill which may predict performance in online geometry problem sets. Based on prior studies, we hypothesize that spatial skills may be more or less helpful depending on how problems are presented. Specifically, geometry translation and rotation problems can be presented in both visuospatial or analytic ways, prompting students to take different strategic routes as they solve each type of problem. In a visuospatial problem presentation, students are prompted to solve the problem using visual perceptual cues and spatial reasoning. Conversely, in an analytic problem presentation, students are prompted to solve the problem with an analytic strategy using a coordinate grid and numeric coordinates. In addition, we hypothesized that spatial skills may affect performance in geometry rotation problems that directly relate to mental rotation skills, but may not impact performance as strongly in translation problem sets which do not as directly relate to mental rotation skill.

To extend prior research examining how spatial skills, specifically in mental rotation, affect performance in mathematics, specifically in geometry, we present a randomized control trial with eighth-grade students in ASSISTments, an online tutoring system. Further, we examine how the effects of mental rotation may differ depending on the type of problem presentation (analytic vs visuospatial) students see, as well as the topic of the problem set within geometry. To examine the different effects which mental rotation skill and problem presentation may have on geometry performance in translation and rotation problem sets, we asked the following research questions:

1. Does mental rotation skill predict math performance in online geometric problem sets?
2. Does problem presentation affect math performance in online geometric problem sets?

3. Does problem presentation moderate the effect of mental rotation skill on math performance within each problem set?
4. Does this relationship change depending on the topic of the problem set (e.g. translations, rotations)?

Methods

Context

The data for this study was collected from February 2015 to May 2017 in ASSISTments, an online tutoring system that features free content for K-12 curricula with a primary focus on mathematics and provides a platform for researchers to run randomized controlled trials (Heffernan & Heffernan, 2014).

This study was originally deployed as available problem sets for 8th-grade content covering translations and rotations within ASSISTments. The problem sets each consists of a pretest on mental rotation and a 10-problem skill builder. In ASSISTments a "skill builder" is a problem set based on Common Core State Standards which present problems in a randomized order on one topic. The goal is for students to "master" a specific skill by answering three problems correctly in a row. Once they answer three problems in a row correctly they are identified as having content mastery of that topic and are labeled as "mastered". If a student answers a problem incorrectly, their count starts over and they keep receiving problems until they get three correct in a row.

Participants

Classroom teachers assigned students to the problem sets. We excluded participants who did not complete the mental rotation task or the problem set. A total of 398 students completed the translations problem set, and 942 students completed the rotations problem set and were included in analyses.

Procedure & Materials

Students completed one of the two problem sets which matched in format. To measure the relationship between spatial skills and math performance, we used the mental rotation task as a measure of spatial skills (Hegarty, 2018). When students opened a problem set, they were first exposed to four mental rotation problems (Figure 1). Upon completion of the four mental rotation problems, they entered a skill builder where they were instructed that they would complete the skill builder if they answered three questions correctly in a row. The skill builder consisted of 10 problems. If a student failed to master the skill builder within 10 problems, they advanced to the posttest but were marked as completing the assignment and were given a skill builder score of 10.

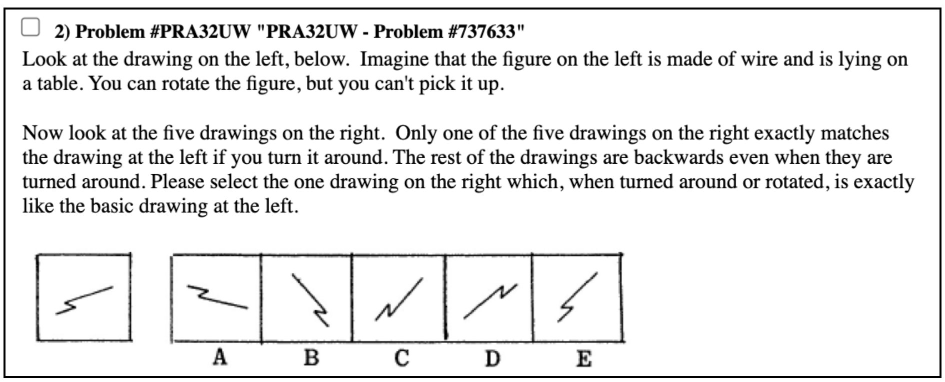

Figure 1. An example of the mental rotation problems students saw

Within each skill builder, students were assigned to one of two conditions, visuospatial or analytic, which differed in how the problems were presented. The visuospatial condition presented the problems to students in a coordinate grid system without gridlines and with starting coordinates (Figure 2 left). The analytic condition presented the problems to students in coordinate grids with gridlines but without starting coordinates, because starting coordinates could easily be inferred by counting squares (Figure 2 right). Hints in the spatial condition also suggested spatial strategies (e.g., “Redraw the triangle on a separate sheet of paper. Then cut it out and try moving it on the graph on your screen.”).

Hints in the analytic condition suggested analytic strategies (e.g., “To translate, you need to start at each point and count 3 to the left and then 2 up.”)

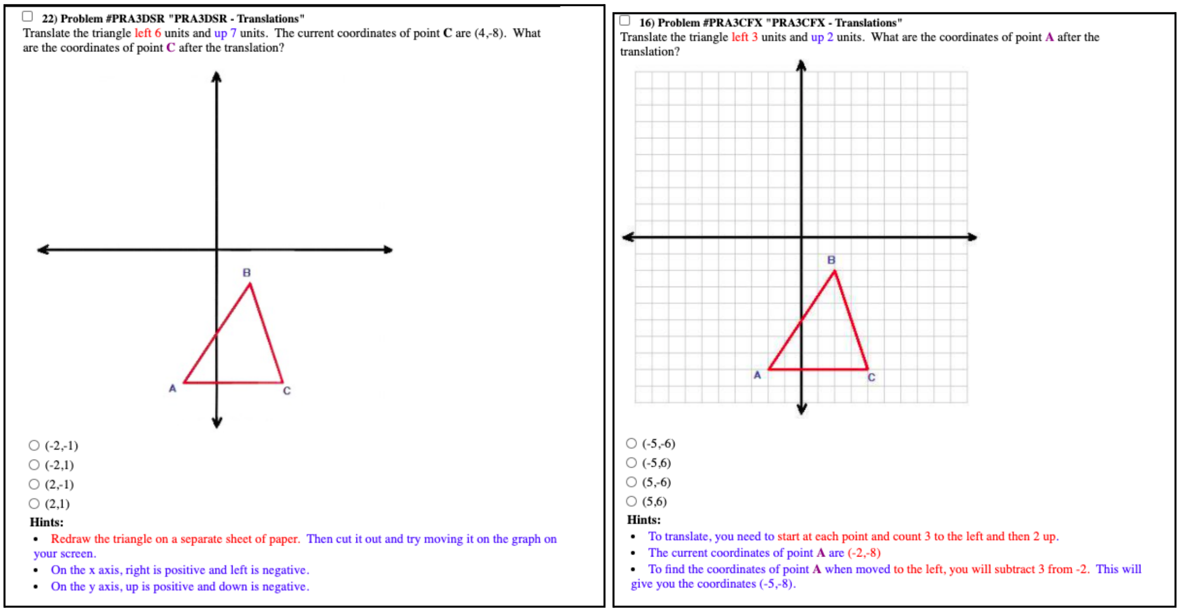

Figure 2. An example of a translation problem and hints in the visuospatial (left) and analytic (right) condition

Measure

To measure the impact of problem presentation and spatial skills on performance we used the following two measures: (1) mental rotation score: this is a measure of spatial skill based on how many questions a student answered correctly out of the 4 mental rotation questions and converted to a percent; 2) mastery speed: this is a measure of how many problems it took a student to complete the skill builder (e.g., correctly answering 3 problems in a row). A lower score for mastery speed indicates that the student solved fewer problems to answer 3 correctly in a row. In other words, they mastered the problem set in fewer attempts.

Approach to Analysis

RQ1: To analyze whether mental rotation skill predicted mastery speed we ran a linear regression with mastery speed as the dependent variable and mental rotation score as a predictor for each problem set.

RQ2: To analyze whether problem presentation (condition) predicted mastery speed we ran an independent sample t-test with mastery speed as our dependent variable and condition as the independent variable for each problem set.

RQ3: To analyze whether mental rotation skill moderated the effect of problem presentation on assignment mastery speed we ran a linear regression with mastery speed as our dependent variable and condition and mental rotation skill as predictors for each problem set.

RQ4: We ran analyses separately for each problem set. To compare whether the effects were the same across problem sets we compared the results of research questions 1-3.

Results

RQ1: Does mental rotation skill positively influence math performance in online geometric problem sets?

For our first research question, we ran two linear regressions predicting mastery speed based on mental rotation score. Within the translations problem set, we found that mental rotation score significantly predicted mastery speed, $F(1, 397) = 28.91$, $p<.01$, $R^2 = .068$. Within the rotations problem set, we also found that mental rotation skill significantly predicted mastery speed, F(1, 941), = 11.60, $p<.01$, $R^2 = .012$. A higher mental rotation score led to a lower mastery score (Figure 1), meaning that participants who performed better on mental rotation mastered the problem set in fewer attempts.

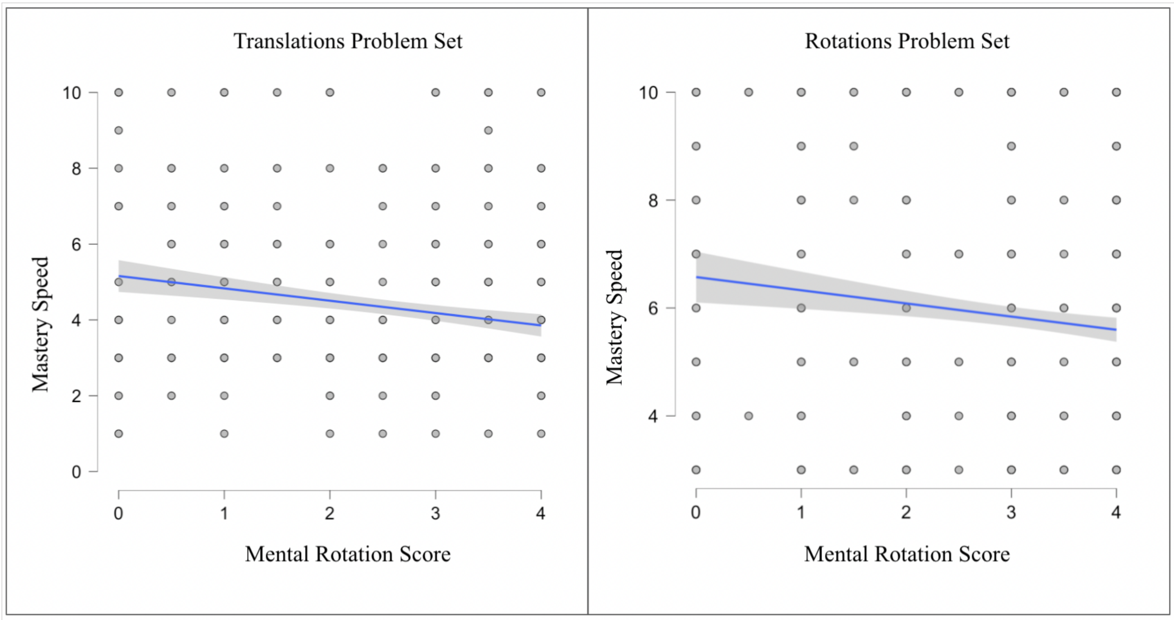

Figure 1. Mastery speed based on mental rotation score for the translations and rotations problem sets

RQ2: Does problem presentation affect math performance in online geometric problem sets?

For our second research question, we ran two independent samples t-tests comparing mastery speed between the analytic and visuospatial conditions for each problem set. For the translation problem set, there were no significant differences between conditions $t(1,396) = 1.28$, $p = .20$. Within the rotations problem sets, there were no significant differences between conditions $t(1,940) = .27$, $p = .79$. Students in both conditions and across problem sets had similar mastery speeds (Table 1).

Table 1. Mastery Speed by Condition and Topic

	Analytic			Visuospatial			
	n	M	SD	n	M	SD	Total n
Translations	205	4.15	1.85	193	4.42	2.32	398
Rotations	470	5.80	2.85	472	5.85	2.85	942

RQ3: Does problem presentation moderate the effect of mental rotation skill on math performance within each problem set?

For our final research question, we ran two linear regressions predicting mastery speed based on condition and mental rotation score. Within both problem sets the interaction between condition and mental rotation score was not significant, $ps > .05$. However, mental rotation score remained a significant predictor of mastery speed across both problem sets.

Discussion

The results from this study confirm prior research by replicating the effects that spatial reasoning skills have on math performance. We found that higher mental rotation scores predicted assignment mastery speed among translations and rotations problem sets in Geometry. Importantly, this association held across both conditions (spatial and analytic), indicating that problem presentation does not impact the effect of mental rotation skill on geometric problem-solving. It is also important that mental rotation scores predict performance not only on the rotation problem set but also on translation problems, as this suggests some transfer or domain generality of spatial skills. In addition, we were able to extend prior research into an online environment, suggesting that spatial skills still matter while learning geometry online. Online learning is especially important right now, so it is important to examine whether the effects of in-person, on-paper learning also extend into online environments so we can learn how to best support students in these increasingly common environments.

While we hypothesized that spatial skills may be more or less helpful depending on how a problem is presented, we were unable to find differences in performance based on problem presentation. However, prior studies have found that students have implemented different strategies based on how problems were presented (Stieff, 2007) or with the use of different representations (Ainsworth, 2006). In our example problems were presented with or without a coordinate grid. While we found no differences in performance, there may have been strategy differences we were not able to detect with our measures.

It is also possible that our specific problem presentations did not sufficiently direct students toward one strategy over the other. Therefore, future studies should look into the specific strategies students employed while solving these problems and possibly iterate on aspects of problem presentation to further support or constrain particular problem-solving approaches.

Further, prior research has suggested that the use of multiple representations and strategies is beneficial to learners (Ainsworth, 1999). Our study looked at each problem presentation and the effect on performance separately. We did not look at the effects of presenting problems in multiple ways to learners or the effect of problem presentation on learning. A future study could include pre and post measures to look at impacts on learning as well as include a condition which presents problems to students in both analytic and visuospatial formats to look at the effects on learning.

In conclusion, we showed that mental rotation skill predicted performance above and beyond problem presentation and that the effect of mental rotation skill is consistent across two types of geometry problem sets. This has important implications for math instruction, as it suggests that students' spatial skills are more important than problem presentation. This reaffirms the importance of engaging students in activities to build their spatial skills and suggests that math teachers' and curriculum designers' time and energy might be better spent designing those sorts of spatial skill-building activities than on designing problems in specific ways to elicit spatial versus analytic strategies.

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Chapter 4. Assessing Preschool Teacher Confidence and Attitudes Toward STEM Through a Professional Development Program

The previous chapters explore different supports we can provide for students during problem-solving in online environments. While exploring student support in mathematics and STEM learning is valuable, this chapter shifts the focus to teachers and how we can support them in teaching math and STEM. Further STEM learning begins early in schooling, and this study focuses on preschool classrooms, where students are beginning to interact with STEM concepts formally, and teachers have the ability to empower and inspire their students to be future STEM leaders.

In Chapter 4, I share the motivation behind, a summary of, and results of the third research project for my dissertation. Over the past two years, through a fellowship, I have helped a team at the AIMS center, https://aimscenter.org/, design, implement and assess a professional development program for Head Start teachers, as well as design, implement, and collect data for a second professional development program centered on coding and computational thinking. I served a leading role in the design of the program activities and sessions and designed all of the tools used to study the implementation of the program and measure teacher attitudes and how they engaged with the program. I have gained valuable skills in the implementation of a research-practice partnership and working with a Head Start program as well as working directly with preschool teachers.

Abstract

The importance of incorporating STEM activities into preschool classrooms is clear. Teacher training in STEM activities is also important in providing students with access to STEM. However, teachers often lack adequate training and confidence in STEM. To address these issues, there is a need for research-based professional development programs to introduce preschool teachers to STEM activities and increase their confidence and attitudes toward STEM. It is also important to measure and assess these programs. The current study introduces a research-based STEM professional development program conducted with 26 Head Start teachers over the course of six months. We explore teachers' reflections of the program by examining monthly reflection surveys and end-of-program interviews. We present evidence of teachers' growth in confidence and attitudes toward STEM teaching and learning. We also present examples of how teachers implemented and expanded the activities from the professional development program into their classrooms. These results have important implications for the design of effective professional development programs in changing preschool teachers' attitudes toward STEM education. Finally, we describe the continuation of this professional development program and the future directions of the program.

Assessing Preschool Teacher STEM Activity Implementation, Self-efficacy and Attitudes Toward STEM Through a Professional Development Program

Motivation & Project Background

Before beginning graduate school, I worked as a preschool teacher for 6 years during my undergrad career. My passions and interests in education research have always stemmed from my experience with young children and as an early childhood educator. Through my first two years of graduate school, I worked on two main projects. The first was a professional development program with middle school teachers to show them how to use an online gameplay and creation platform that supports STEM learning. I really enjoyed working with teachers and seeing their confidence in instructing a STEM topic grow. The second project was focused on exploring how preschoolers can learn math skills through gameplay. I enjoyed seeing firsthand how preschool students can improve their math skills through games. During my time at the preschool, I often noticed how many teachers had negative attitudes toward math and STEM in general, often stemming from their own lack of confidence and knowledge in the subject. Further, I noticed the lack of training opportunities focused on STEM concepts, and the few available were not designed to keep the teachers engaged. These experiences motivated me to leverage my graduate studies to be more involved in both teacher training and early childhood education.

As I progressed in my graduate training, I had plans to run another study on preschoolers' learning from games; however, the COVID-19 pandemic hit two months before I presented my master's thesis on my first two projects, and my future plans pivoted. From 2020-2022, it was virtually (haha) impossible to enter early childhood classrooms as a researcher, for various and well-justified reasons. In addition, teachers were asked to go beyond their normal job description during these past two years, so asking them to participate in even more training seemed unfair, and even if we did ask, the participation would likely be low. So, to respect early childhood restrictions, and respect the toll that has been put on teachers, I shifted my research focus from teacher training and early childhood to more pandemic-accessible topics: learning supports in online platforms. This shift in research topic was timely as students were now using online platforms more than ever during the pandemic. However, this is not where my passions lie.

During the pandemic in Fall 2020, when everything went virtual, I was lucky enough to connect with Dr. Paul Reimer, the executive director of the AIMS center. The AIMS Center is a non-profit education center focused on “supporting playful, human-centered, and culturally sustaining approaches to teaching and learning mathematics and science” that works with preschool through college-aged students and teachers. They form various partnerships with local school districts and education programs in Fresno, California, where they are located. They help to design STEM curriculum and activities for teachers and students in fun and engaging ways, while also providing professional development opportunities. Taking full advantage of the virtual world allowed me to connect with a company located on the opposite coast, and Paul invited me to attend some of the trainings with Head Start preschool teachers that the AIMS center hosted throughout the 2020-2021 school year. I loved attending these training sessions as an observer and got to experience how a research-practice partnership functions. I observed four different professional development trainings and was inspired by how well the presenters were able to entice the audience to participate, even through Zoom. It was great to see the different activities centered around STEM that the teachers were learning. And it was FUN!

Fast forward to last fall, specifically September 2021, when I was beginning to think about which topics I could propose for my dissertation project. I was lucky enough that the AIMS center was offering a fellowship for graduate students to help them with some of their projects. I applied and earned an offer for the fellowship! I began working with the AIMS team to design and study a professional development program in partnership with a local Head Start center. The project combined my interests in early childhood education and teacher training, which I was passionate about. It also gave me access to teachers, schools, and students, which was still hard to gain with the pandemic restrictions still in place. The fellowship gave me the perfect opportunity to continue to explore my interests and gain valuable experience working outside of academia and in a research-practice partnership and gain experience working with others from backgrounds that differed, both professionally and personally, from my own. I am also lucky enough that I was able to continue the fellowship through the 2022/2023 school year and extend the work on this project to design and conduct another professional development program with the AIMS team.

Through the fellowship, I oversaw designing the tools to evaluate the professional development program and gain feedback on the program itself. I was also in charge of collecting and analyzing the data. During this experience, I designed a study for my dissertation which looks into teachers' reflections of the program and of their personal growth in regard to the program, as well as how they were able to adapt and implement different activities they learned from the professional development into their classrooms. I have also mentored and trained an undergraduate research assistant, introducing her to qualitative research and guiding her as she began her research journey.

I am excited about the experience this fellowship has given me, and about the novel and detailed conclusions that can be drawn from using more qualitative methods to uncover new things about early childhood educator STEM professional development. In addition, it has been extremely rewarding to see the direct, positive impacts of this research-practice partnership on the teachers and the students. While there is no specific “data” to see this real-world impact, it has been great to just observe through my interactions with the team, the teachers, the students, and their families. One of my favorite quotes shared by a teacher who completed the program is, *"it's really teaching them these little foundations and connections to open the doorway for all learning."*

Introduction

The importance of integrating STEM education into preschool classrooms has been echoed across contexts (Chesloff, 2013; National Research Council, 2011). However, teachers' low confidence and negative attitudes toward STEM, combined with few opportunities for professional development, have resulted in an avoidance of STEM teaching (Timur, 2012). Effective professional development programs provide opportunities to improve teachers' confidence and attitudes toward STEM and are crucial to the success of preschool programs that serve as the foundation for future success in STEM fields (Hamre et al., 2017). Prior studies have shown that effective professional development includes developmentally appropriate instruction, individual coaching (Bowman et al., 2001), group-focused interventions (Ginsburg et al., 2006), and modeling instruction (Wasik et al., 2006). However, professional development workshops may provide only one of the aspects mentioned above, which is inadequate and may not be of high quality (Gomez et al., 2015). Further, common professional development programs for preschool teachers lack research-based practices and are not monitored for content and effectiveness (Gomez et al., 2015). The current study evaluates a professional development program aimed to fill gaps in preschool teachers' STEM engagement and training. The program was designed to introduce STEM activities to preschool teachers, enhance their understanding of STEM concepts and provide opportunities to implement STEM activities in their classrooms, with guided support. The professional development was designed around several research-based practices, including developmentally appropriate instruction, individual coaching, group-focused interventions, and modeling. Further, throughout the professional development, we used participant feedback to iteratively reflect on and adapt our approach with teachers. The current study examines teacher reflections as they participated in the program as well as how they implemented and adapted activities from the professional development in their classrooms.

Theoretical Background

STEM in Early Childhood Education

Integrating STEM into early childhood classrooms has been shown to benefit students (Chesloff, 2013; Clements & Sarama, 2016; National Research Council, 2011). Early childhood skills in STEM, and specifically math, have been shown to indicate success in later math and literacy development (Duncan et al., 2007; Nguyen et al., 2016). The educational skills that children learn in early childhood contexts and enter kindergarten with are strongly predictive of later academic advantages (Denton & West, 2002; West et al., 2000). Exposure to high-quality early childhood education is related to later cognitive and academic outcomes and may be especially important to children at risk (Campbell et al., 2002; Reynolds et al., 2002). Therefore, it is especially important to make sure preschool children have access to quality STEM experiences.

Teacher Confidence in STEM Teaching

There is a growing emphasis on integrating STEM education into schools (Chesloff, 2013; National Research Council, 2011), however often teachers who have little or no background or training in STEM are the ones expected to instruct in STEM fields (Akerson et al., 2018; Johnson et al., 2016; Siegel & Giamellaro, 2021). It has been shown that teachers' low confidence and negative attitudes toward STEM, combined with few opportunities for professional development, have resulted in an avoidance of STEM teaching (Timur, 2012). However, quality professional development programs have the potential to increase teacher self-efficacy and attitudes towards STEM and introduce them to novel STEM activities they can implement in their classrooms.

Professional Development for Early Childhood Educators

Preschool students are often taught by teachers with little education (LoCasale-Crouch et al., 2007), with less than half of early childhood educators holding baccalaureate degrees (Saluja et al., 2002). Further, even with the proven importance of early childhood math and STEM skills related to later outcomes in life (Denton & West, 2002; West et al., 2000), there remains a lack of professional development opportunities in these areas (Schoenfeld & Stipek, 2011; Simpson & Linder, 2014). Early childhood teachers often do not receive the same training and teacher preparation as K-12 teachers prior to entering the classroom (Ginsburg et al., 2006). Early childhood educator preparation programs have been known to not provide enough attention to developmentally appropriate practices in teaching specific academic content (Bowman et al., 2001). To fill the gaps in education, training, and confidence, it is important to provide teachers with effective professional development programs and opportunities to explore STEM concepts. Specifically, evidence indicates that teachers' instruction is a strong factor in promoting children's active involvement in learning (Hamre & Pianta, 2005; Lieber et al., 2009). Professional development is one approach to increase instruction quality in early childhood education; however, there is little evidence reporting effective professional development programs that have been able to significantly change instructional practices (Lieber et al., 2009).

There are a few factors that have been proven to be part of an effective professional development program. First, programs should provide opportunities to increase teachers' confidence and improve attitudes toward STEM (Hamre et al., 2017) and there should be ways to credibly measure this growth. Next, programs should provide developmentally appropriate instruction (Bowman et al., 2001). Third, programs should provide group-focused instruction (Ginsburg et al., 2006). Fourth, professional development programs should be research-based and monitored for effectiveness (Gomez et al., 2015). Lastly, individual coaching or mentoring has been shown to be a particularly effective aspect of professional development programs in the form of on-site support (Bowman et al., 2001; Dickinson & Brady, 2006). Teachers may typically receive little one-on-one feedback from their supervisors and appreciate the added feedback and valued relationship with an individual coach (Lieber et al., 2009). Since most professional development opportunities only provide a select few or none of these factors, existing professional development programs tend to lack effectiveness and are difficult to implement successfully (Clements & Sarama, 2016; Gomez et al., 2015).

Effective professional development programs engage teachers as active participants, rather than expecting them to passively absorb new information and implement it (Siegel & Giamellaro, 2021). Teachers bring their own experience, knowledge, practices, attitudes, identities, and needs into their professional development learning (Datnow et al., 1998; Johnson et al., 2016). Acknowledging teachers' perspectives and allowing them to be active participants in the program can impact the long-term success of professional development programs (Siegel & Giamellaro, 2021). The design and implementation of the current project take into account the factors which make up effective professional development programs, and purposefully include the teachers as active participants in each of the training sessions, by acknowledging and incorporating the experiences they bring into each training.

The Current Study

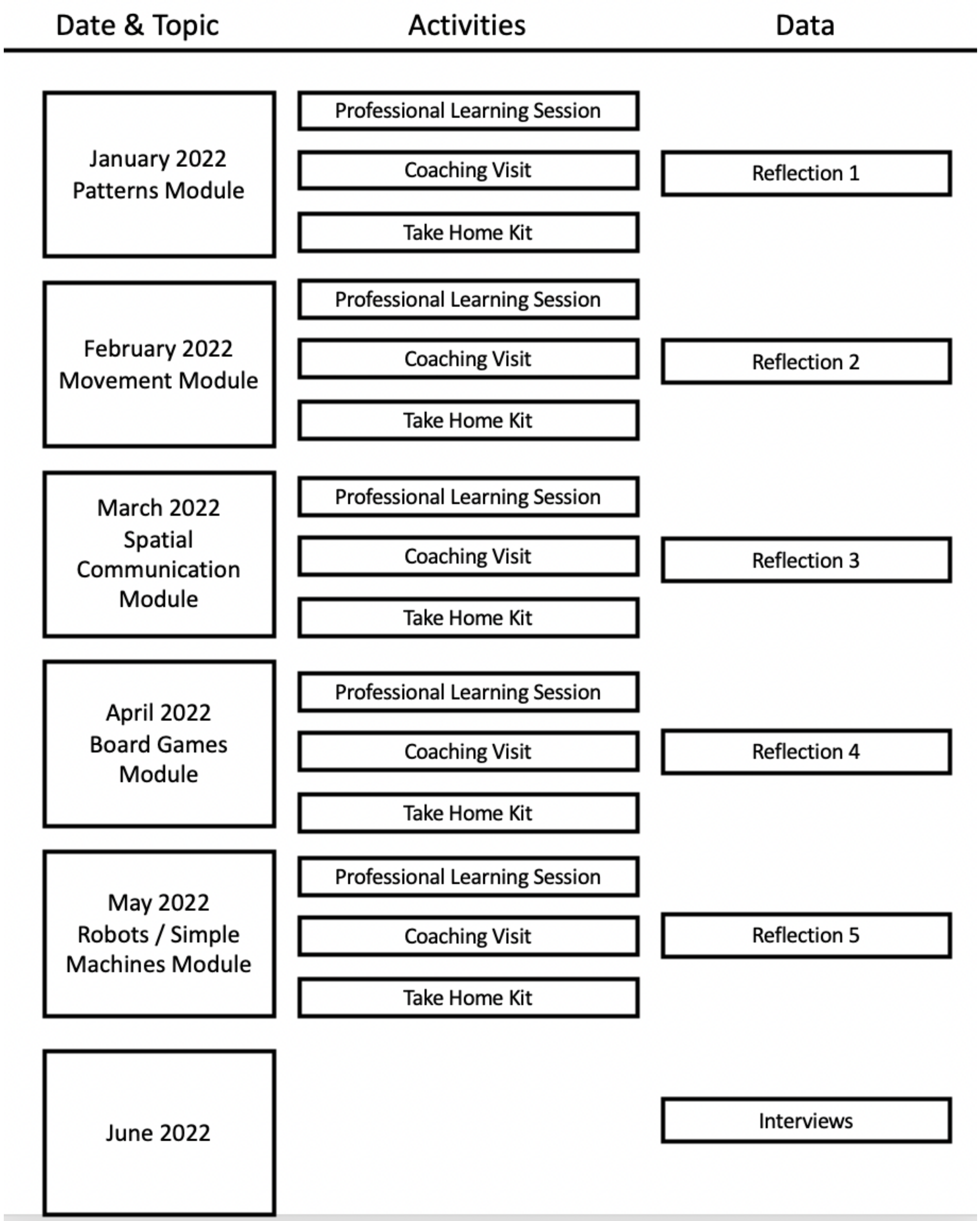
The current project has two overarching goals: 1) to continue a research-practice partnership with a local Head Start center, and 2) to examine the benefits of the program for teachers. The broader goals of the larger professional development project and research practice partnership are to 1) increase access to STEM education experiences in early childhood, 2) increase early childhood teachers' confidence attitudes towards STEM teaching and learning, and 3) provide quality professional development opportunities to Head Start professionals. Within the scope of the project in general, the goals of this dissertation are to 1) identify changes in teachers' attitudes and confidence towards STEM teaching and 2) explore the ways in which teachers were able to implement and expand the STEM activities presented in the professional development. We aim to answer the following research questions:

1. How do teachers' attitudes and confidence toward STEM change after participating in the professional development program?
2. In what ways do teachers implement and expand activities presented in the professional development program?

Professional Development Program Overview

We examined data collected during a six-month professional development program and partnership with a central California Head Start center beginning in January 2022 and running through June 2022. The professional development team included me, a team of two other researchers, and four professionals in teacher training, each having experience in teaching and coaching and holding a master's degree in Math or STEM education. This partnership included the teachers as active co-participants, rather than individuals to be taught. Each month of the program covered a different STEM topic (Figure 1). The module topics were chosen by the AIMS team intentionally. The five topics all build off of one another to create a cohesive program, each being distinct enough and having specific activities which are connected to each concept. The five topics include Patterns, Movement, Spatial Communication, Board Games, and Robots (Appendix F). Each topic builds off of the previous topic so that the final topic of robots/simple machines encompasses all prior topics. Patterns are a building block to other STEM concepts and are a solid and familiar foundation to start with. Moving on, spatial communication is often communicated via pattern. We then use this spatial communication to move effectively and communicate about different movements. We then use movement, spatial communication, and patterns to effectively learn and play different board games. Finally, robots and simple machines make use of effective patterning and spatial communication in order to move effectively and are similar to board games in that there are specific directions and commands for a robot to follow. Each module of the professional development program consisted of professional learning sessions, coaching meetings, family take-home kits, and reflection questions. Additionally, in the final month, a subset of teachers completed interviews with a researcher on experiences throughout the program (Figure 1). Each aspect is described in more detail below.

Figure 1. Overview of the Professional Development Program



Professional Learning sessions

There were a total of five professional learning sessions throughout the entire professional development program. Professional learning sessions occurred once a month for five months, with a final celebration and conclusion session to finish the six-month program in June. Each professional learning session was two hours in length and followed a similar format. Professional learning sessions each focused on a different topic of STEM learning matching each module's topic: patterns, spatial communication, movement, board games, and robots/simple machines (Table 1). Due to the COVID-19 pandemic, the first two professional learning sessions were held virtually over Zoom and the final three were held in person at the Head Start center.

Each professional learning session consisted of three distinct sections. Participants experienced STEM concepts as a learner, observer, and finally teacher of STEM (Figure 2). Each professional learning session ended with time to schedule a coaching visit as well as fill out a four-question reflection on the teacher's experience during the session. The activities of each session are described below in more detail.

Figure 2. Overview of Professional Learning Sessions from the Head Start Partnership Annual Report (2021-2022) https://aimscenter.org/pk12-partnerships

PROFESSIONAL LEARNING

Teachers working collaboratively to form a geometric shape with a stretchy band.

Each Professional Learning Session helped to develop teachers as Learners of STEAM, Teachers of STEAM and Observers of children's STEAM. The professional learning experiences that took place during each 2-hour session engaged teachers in STEAM learning and challenged them to look forward with new innovative techniques to create STEAM learning experiences for children. In each session, teachers were encouraged to reflect on their own experiences and how these could shape their work with young children.

Each session emphasized the importance of an embodied approach to learning, allowing the teachers to experience the activities themselves while exploring ways to facilitate them with their students. One teacher expressed that the "hands on experience of how children can react or (what they might) need when the activities are done" was the most helpful aspect of the sessions. Another teacher stated how they appreciated the active and creative nature of the professional learning experience.

Head Start teachers explore how games can facilitate STEAM learning by working collaboratively to get the ping pong ball in the hole.

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Table 1. Overview of Professional Learning Sessions

professional learning session topic	N Participants	Overview	Take Home Activity
Patterns	13	*Learner:* complete a variety of patterns using different manipulatives. *Observer:* Reflect/brainstorm on where they observe patterns in their daily life and in their classroom *Teacher:* Explore activities related to visual, movement, sound, art, and environment patterns	*Dancing Patterns Game:* spin a spinner to indicate which dance moves to do in a row, repeat this pattern! *Picking out patterns:* use nature objects (leaves, sticks) to represent a dance move, lay out objects in a pattern, then dance your pattern! (Appendix A)
Spatial Communication	17	*Learner:* Participants form groups to give an AIMS team member directions from his car to the Head Start front door. Directions are read off and team member follows exactly what they say, leading to issues. In the third round, participants cannot use identified spatial words in their directions. *Observer:* Reflect on where and when they use spatial communication in their classrooms *Teacher:* Stations, guess my design, grid treasure chest, embodied spatial communication	*Hide the Animal* *ISpy Scene* (Appendix B) *Find the Ball* *Bean Bag Song* (Appendix B)
Movement	23	*Learner:* Parachute and Beachball, exploring movement on the giant grid/tarp *Observer:* Reflect on how they have implemented spatial communication since last PL *Teacher:* Interactive Yoga & Feed the Monster Game	*Feed the Monster Game:* Spin a spinner indicating a movement, roll a dice indicating the amount of food to bring. Do the movement towards the monster while holding food to feed it! *Interactive Yoga:* Yoga cards show images of a pose with a stuffed animal incorporated. Use spatial communication to describe and enact placement of animal (on my

			head) (Appendix C)
Board Games	18	*Learner:* Play different versions of hopscotch around the world! *Observer:* Reflect on movement implementation *Teacher:* Introduce frog splash game	*Frog Splash:* Children take turns spinning a spinner which indicates how many lily pads to move their frog game piece on one of 4 game boards. *Embodied Frog Splash:* Giant colored lily pads laid out on the floor; adults yell out which color lily pad to hop to! (Appendix D)
Robots / Simple Machines	15	*Learner:* Teachers follow directions given to them as they move in different directions on a life-size grid as if they were a robot following coding instructions. *Observer:* Reflect on experiences so far, how you are using spatial language, how are children using take-home kits, how are children interacting with STEM content, etc. *Teacher:* Teachers practice the embodied catapult and wheel and axel activities	*Embodied Catapult* (Appendix E) *Wheel and Axel*

Take Home Kits

Aligning with the topic of each professional learning session, the professional development team created a “take-home kit” for each child to bring home to their families (Figure 3). These kits were designed to encourage family involvement with STEM, using commonly found objects. Take-home kits consisted of one developmentally appropriate activity which a child could explore at home with caretakers (Table 1). The teachers were able to explore the take-home kits during the professional learning sessions and had the opportunity to use them as part of their classroom instruction if they chose to.

Figure 3. Summary of Take Home Kits from the Head Start Partnership Annual Report (2021-2022)

https://aimscenter.org/pk12-partnerships

TAKE-HOME KITS

This year every student received five AIMS Take-Home Kits. The kits were created to correspond with the Modules for Professional Learning and provided a rich opportunity for a classroom connection to the home. The kits playfully engaged children in STEAM learning while being simple enough for parents to use. Materials were selected with the purposeful intent of being simple, inexpensive, and interchangeable to show that learning arises from what children do with the materials- relying on their natural curiosity and creativity- and not necessarily the materials alone. Five new kit collections were introduced in 2021-22:

→ **Patterns**

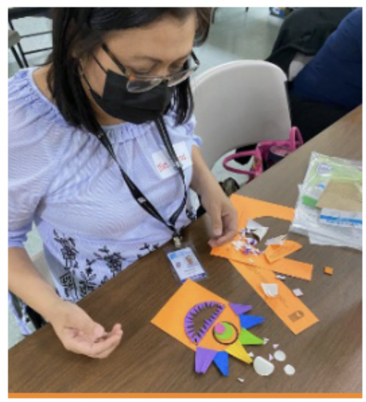
→ **Spatial Communication**

→ **Movement**

→ **Games**

→ **Simple Machines**

Along with the kits for students to take home, each classroom received a Hexbug kit. Also, three Matata Lab Robotic Kits are now available for classrooms to check out and provide coding experiences for students.



A teacher experiencing the Feed the Monster game in the Movement take-home kit.

The Frog Splash games were a real hit with students. They hopped their frog across a pond as they experienced counting, one to one correspondence, as well as spatial reasoning in the board game version of Frog Splash.

In the embodied version they created their own frog headband and hopped from lily pad to lily pad as they used spatial language such as forward and backward, up and down, higher and lower, etc.

Game take-home kit contents included:

- 4 Frog Splash game boards
- 4 toy frogs
- 4 lily pads
- 3 spinners
- 1 frog headband craft.

Coaching Visits

Each teacher was assigned a classroom coach to work with throughout the six-month program. There were five coaches total, who were members of the professional development team at AIMS, and all had prior experience as classroom coaches. Each coach was matched with one to three classrooms. Coaches met with teachers once a month between each professional learning session. These visits included virtual meetings as well as virtual and in-person classroom visits to observe and assist with STEM activities (Figure 4). Coaches kept a log of each of their coaching visits with teachers indicating the date, time, location, and summary of activities during the coaching visit. There were five coaches in total who were each assigned one to three classrooms to work with. Each classroom consisted of two to four teachers and teacher assistants.

Figure 4. Summary of Coaching Visits from the Head Start Partnership Annual Report (2021-2022) https://aimscenter.org/pk12-partnerships

COACHING

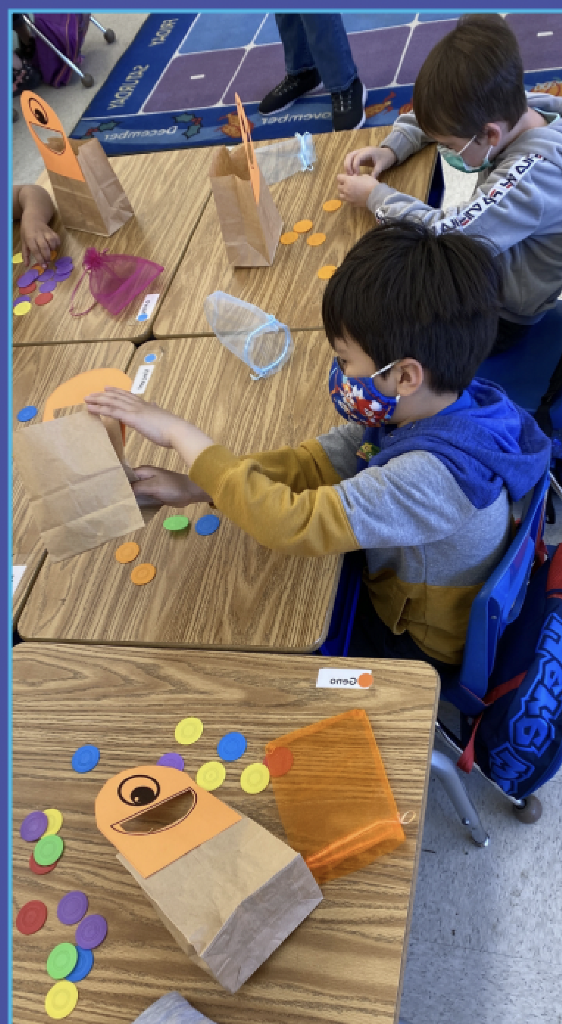
Each classroom received the added support of coaching to implement ideas and content from their learning. Classrooms were assigned a coach that would support planning and integrating activities as well as be available for questions. Coaches would make at least one classroom visit to observe the implementation of one activity and offer feedback. At the end of each professional learning experience, teachers made appointments with an assigned coach and decided on what activity they would like to try from the current module theme.

CLASSROOM VISITS

On the day/time agreed coaches would make classroom visits. Teachers and teacher assistants would decide which person would lead an activity for the observation. If requested, coaches would model the activity before or during an observation.

FEEDBACK

The coaching relationship was not evaluative but instead built on the idea of transparency and mutual respect. Coaches would share feedback from observations based on what they noticed children doing and saying. Focusing on children's learning was central in reflection discussions. The coaching relationship sought to foster trust and hold a safe space so that teachers could be vulnerable as they learn and apply new ideas. Classroom staff were encouraged to feel free to ask questions, share ideas, and discuss challenges.



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Methods

Participants

Participants included 26 central California Head Start preschool teachers and teacher assistants who taught 131 children across eight classrooms with each classroom having between two to four teachers. This Head Start center was selected for participation based on previous relationships, willingness to participate, and administrative support. Participants did not receive compensation for their participation in the professional development program, as it occurred as part of their normal work hours and satisfied their professional development requirements. However, participants received a $20 Amazon gift card for their participation in the exit interview since it occurred outside of their normal work hours.

The Head Start program in this study served neighborhoods and communities comprised largely of Latinx and Black populations. As a white, female researcher from a STEM-based University in the Northeast, I recognize my differing perspectives and daily lived experiences from the participants in this study. As a fellow early childhood educator, with over ten years of experience working with preschool-aged children, I was aware of this common experience that I shared with participants; however, I also acknowledge that my experiences were with a different population of students. Due to my experience as an educator in a preschool with adequate funding and support, as well as my positionality as a white researcher, I recognized and sought to maintain sensitivity to certain barriers which these teachers may face. I also engaged in continuous and transparent dialogue with other team members to surface and address any biases that might have arisen in my own interpretations of teachers' activities or attitudes.

Measures

Reflections

At the end of each of the five professional learning sessions, teachers filled out a four-question open-ended reflection worksheet. The first three questions were the same across each session: 1) What did you enjoy/found positive about today's session? 2) What was difficult/challenging about today's session? and 3) How could we more effectively lead today's session in the future with other teachers? The final question was specific to each session (Table 2).

Table 2. Professional Learning Reflection Questions

Professional Learning Session Topic	N responses	Final Reflection Question
Patterns	13	What patterns are you now noticing in your daily life? personal experience? Community?
Spatial Communication	17	What are some ways you might experience spatial communication inside your classroom? Outside your classroom? What forms does this communication take?
Movement	23	What are some ways children move inside your classroom? Outside your classroom? What might be some ways you have been able to connect spatial communication or patterns (from previous Modules) to movement?
Board Games	18	What do you think your students may learn from playing board games?
Robots / Simple Machines	15	What do you think your students may learn from making simple machines and playing with robots?

Interviews

A subset of 13 teachers also participated in 20-minute semi-structured exit interviews asking about their overall experience with the program, classroom implementation, expansion of activities, and growth as a preschool teacher of STEM (Table 3).

Table 3. Interview Questions

Question
1. Can you start by introducing yourself?
2. How did you get involved in Head Start preschool?
3. What do you enjoy about teaching preschool? What do you find challenging or less enjoyable?
4. Do you think preschool STEM education is important? Why do you think preschool STEM education is important? Probe: What skills do you think STEM education should help students develop?
5. What skills do you think your students can develop by participating in STEM learning?
6. What is one STEM activity you used in your classroom before participating in the professional learning sessions?
7. What is one activity from the PLs you tried in your class? Did it go well? Why or why not? How can you improve for next time?
8. Did you adapt or change any of the activities from the professional learning sessions to fit your classroom and students' needs? In what ways did you adapt the activity?
9. What is one challenge you faced with incorporating STEM activities into your classroom?
10. What strategies, methods, and techniques do you use for preschool STEM education?
11. Think back to yourself at the beginning of the program, compared to now. Which part of the project was the most beneficial to you? Probe: professional learning sessions, Coaching sessions

Measures of Fidelity

Throughout the program, multiple measures of fidelity and participation were collected. As a measure of participation, attendance in each professional learning session will be calculated based on reflection completion. If a teacher turned in a reflection sheet at the end of the PL, she was marked as in attendance. The presented numbers for attendance are not 100% accurate, as some teachers did not fill out their names on reflections. Further, some teachers moved classrooms or no longer work for Head Start. These situations will be considered on a per-person basis.

Coding Guide and Process

We conducted a thematic analysis to qualitatively code the different sources of data we collected during and after the professional development program (Maguire & Delahunt, 2017). Our first goal was to identify conversations around teacher growth and changes in attitude and confidence, and emotions toward STEM teaching, in line with our first research question. Our second goal was to identify conversations around the implementation of specific activities and concepts from the professional development in the classroom. We also aimed to identify barriers to STEM integration and professional development completion and feedback on professional development activities to inform future design. These two goals are a part of the larger project and go beyond the current study goals. Two coders, with the help of two AIMS team members for guidance and discrepancy discussions, met regularly over the course of seven months to discuss codes, larger themes, and to code each of the data sources. The coders met and agreed upon each code, so inter-rater reliability was not calculated. The process is laid out in detail below.

Coding Process

Step 1: Become familiar with the data

Both researchers reviewed all sources of qualitative data and read through each response to familiarize themselves with the data. Coders read (or re-read) each transcript and reflection. Coders noted any initial reactions and thoughts.

Step 2: Generate initial codes

The coders met to discuss common overall themes and areas of interest they identified across data sources. Additionally, they discussed specific areas of interest and themes in regard to the research question and the implementation of activities. Since we had specific research questions and goals in mind, we conducted a theoretical thematic analysis. From our generated list of codes and themes, we then coded each piece of data line-by-line independently. We met bi-weekly to compare our individual codes and come to a consensus on any discrepancies.

Step 3: Review and define themes and codes

After coding the data, the team met to discuss the themes and codes and define each of them in the context of the project.

Step 4: Identify patterns across participants and sessions

Data was organized by participant, with each teacher's reflections and interview responses contained together. Researchers then looked across the themes and codes present for each participant to identify patterns. Patterns were also explored in response to each of the research questions and are shared in the results section.

Code Book

We organized our individual codes under the larger themes we were interested in. We identified the larger themes based on our research questions, from reading through the data, and from our experiences in conducting the professional development program. I, the undergraduate research assistant, and two AIMS team members decided on the overarching themes together. Each is described below (Table 4), along with the goal of the overall theme in what conclusions and outcomes we aimed to draw from data represented within that theme.

Table 4. Theme descriptions and goals

Overarching Theme	Description and Goal
Growth	Under this theme we aimed to detect specific instances where teachers mentioned any change or growth in their attitudes, practices, or knowledge. The goal of this overarching theme was to detect evidence of teachers' growth and change as a result of the professional development program
Implementation	Under this theme we were interested in any comment regarding the implementation of any of the professional development activities or STEM concepts into a teacher's practice and classroom. This included any comments about expanding activities, success, and challenges with implementation and comments about observations of student interactions with activities. Further, this overarching theme also includes teachers discussing how they plan to implement activities into their classroom and how they see fit, whether incorporating activities into their already existing curriculum or making connections from concepts from the activities and the professional development program to activities, methods, topics, and everyday classroom functions which they are already doing. From this theme, we aimed to determine how successful teachers were in implementing activities, detect any difficulties and assess how well they were able to connect the concepts and activities to their existing classroom and curriculum.
Barriers	Through conducting this professional development and through reading the responses from teachers, the research team decided that it was important to go beyond our research questions and include an overarching theme of the barriers which teachers may face in attending professional development programs as well as implementing activities and any barriers in their everyday teaching. These barriers are important to identify and describe, as they are an important part of the teaching profession and may impact the future design of professional development programs. Further, it is important for researchers to be aware of these barriers that teachers face. Within this theme, we aimed to identify barriers including access to materials, limits on time (whether planning, personal, or classroom time), barriers regarding the age of their students, logistical barriers (such as staffing and classroom management), technology barriers, language barriers, and barriers regarding the larger exosystem of their students and themselves (Swick & Williams, 2006). The goal of this overarching theme was to identify what barriers exist for Head Start preschool teachers.
Emotion	The overarching theme of emotion was included to explore how teachers felt about the professional development program, their students, their teaching practice, and themselves. We aimed to identify emotions including; curiosity, anxiousness, confidence, any personally related issues unconnected to the program, any concerns about their personal health or the health of their students and families, and any discussion of their identity as an educator. The

	goal of this overarching theme was to uncover how teacher emotions relate to the professional development program and how their emotions may have changed throughout the program.
Activity Feedback	The overarching theme of activity feedback was used to identify specific instances of teachers providing feedback about the specific activities they participated in during the professional development program. This did not include feedback on the activities they used in their classroom, as that is captured in the implementation theme. This theme was used to collect feedback on teachers' participation in the program and on the specific components of the program. We included feedback on the hands-on and interactive nature of the program activities, comments about how engaging the activities were, any discussion of the difficulty or ease of the activities, and reflections on how the teachers could see their children learning from these activities or any specific skills or concepts they may learn.

Within each of the larger themes, we identified individual codes. Each of the codes is defined below, within each larger theme (Table 5).

Table 5. Code descriptions

Overarching Theme	Code	Description (Professional Development (PD)
Growth		
	Change in attitude	When a teacher talks about how she felt before PD and feels now, or any new attitudes she holds
	knowledge gain	Anytime a teacher mentions new knowledge such as, "I learned…", "I learned this about STEM…", "I thought this before but now…"
	change in practice	When a teacher talks about how she taught before the PD and now or any new teaching practices
Implementation		
	expansion	when a teacher discusses an adaptation to an activity
	success	a positive report around the activity
	challenges	a difficulty when implementing the activity
	student evidence	how children (or one child) interacted with an activity
	incorporate into existing curriculum	How specific activities fit into their current classroom practice

	Connect to existing practice	Connecting PD concepts to current classroom practice ... or making connections from concepts to everyday life
Barriers		
	materials	access to materials as a problem
	time	time as a problem
	age	issues regarding the age of their students
	knowledge	lack of knowledge of themselves or their students
	logistics	discuss staffing issues, dealing with behaviors or classroom management
	technology	discuss zoom issues, internet issues or any technology related problem
	language	language as a problem
	exosystem	any outside barriers including school board decisions, funding sources, upper management, or city / state expectations & regulations
Emotion		
	curiosity	talk about wanting to learn more, explore more or excitement for what is to come
	anxiousness	talk about hesitations or being nervous
	confidence	anytime they talk about confidence
	personal	discussing personal life
	health	talk about their own or broader communities' health
	educator identity	talking about excitement, passion, or identity as an educator
Activity Feedback		
	Hands on	talk about the hands-on nature of the activities during the professional learning sessions
	engaging (teachers)	about an activity from professional learning session being fun, engaging or incorporating teamwork
	difficulty	talk about an activity from a professional learning session being easy or hard
	children's learning	teacher discussing skills, knowledge, concepts they believe students may learn from an activity

Code Frequency

For the reflection responses, we coded each response to a question fully under one of the above codes. Therefore, we were able to determine the percentage of total responses in which each code was coded across the reflections. Below shows how often each code was used across the reflection surveys (Table 6).

Table 6. Code instances across reflections

Theme	Code	N instances	% of total reflection responses
Activity Feedback			
	Children's Learning	31	9.01%
	difficulty	37	10.76%
	engaging	61	17.73%
	hands-on / interactive	10	2.91%
Barriers			
	age	1	0.29%
	Exosystem	1	0.29%
	knowledge	2	0.58%
	language	0	0.00%
	logistics	2	0.58%
	materials	2	0.58%
	technology	3	0.87%
	time	5	1.45%
Emotion			
	anxiousness	0	0.00%
	confidence	0	0.00%
	curiosity	0	0.00%
	Educator Identity	0	0.00%
	Personal	2	0.58%
	health	1	0.29%
Growth			
	Change in attitude	0	0.00%
	change in practice	3	0.87%

	knowledge gain	13	3.78%
Implementation			
	Challenges	4	1.16%
	Connect to existing practice	43	12.50%
	expansion	1	0.29%
	incorporate into existing curriculum	1	0.29%
	Student evidence	1	0.29%
	success	0	0.00%

We also determined the number of instances of each code across the interview responses. However, due to much longer responses within each question, and the conversational nature of interviews, each response was broken down and different parts of the responses were coded so we are unable to determine the percentage across total responses (Table 7). We included the percentage of each code in regard to the total number of code instances across interviews.

Table 7. Code frequency across interviews

Theme	Code	N instances	% of all codes
Activity Feedback			
	Children's Learning	0	0.00%
	difficulty	0	0.00%
	engaging	8	3.52%
	hands on / interactive	4	1.76%
Barriers			
	age	10	4.41%
	Exosystem	5	2.20%
	knowledge	13	5.73%
	language	2	0.88%
	logistics/management/ staff	12	5.29%
	materials	8	3.52%
	technology	1	0.44%

	time	10	4.41%
Emotion			
	anxiousness	4	1.76%
	confidence	4	1.76%
	curiosity	4	1.76%
	Educator Identity	15	6.61%
	Personal	1	0.44%
	student/family/personal health	6	2.64%
Growth			
	Change in attitude	9	3.96%
	change in practice	9	3.96%
	knowledge gain	19	8.37%
Implementation			
	Challenges	10	4.41%
	Connect to existing practice	11	4.85%
	expansion	19	8.37%
	incorporate into existing curriculum	12	5.29%
	Student evidence	11	4.85%
	success	20	8.81%

We also determined the total number of each code across both interviews and reflections as well as the percentage of each code in regard to the total number of code instances (Table 8).

Table 8. Code frequency across interviews and reflections

Theme	Code	N instances	% of all codes
Activity Feedback			
	Children's Learning	31	6.87%
	difficulty	37	8.20%
	engaging	69	15.30%
	hands on / interactive	14	3.10%
Barriers			
	age	11	2.44%

	Exosystem	6	1.33%
	knowledge	15	3.33%
	language	2	0.44%
	logistics/management/staff	14	3.10%
	materials	10	2.22%
	technology	4	0.89%
	time	15	3.33%
Emotion			
	anxiousness	4	0.89%
	confidence	4	0.89%
	curiosity	4	0.89%
	Educator Identity	15	3.33%
	Personal	3	0.67%
	student/family/personal health	7	1.55%
Growth			
	Change in attitude	9	2.00%
	change in practice	12	2.66%
	knowledge gain	32	7.10%
Implementation			
	Challenges	14	3.10%
	Connect to existing practice	54	11.97%
	expansion	20	4.43%
	incorporate into existing curriculum	13	2.88%
	Student evidence	12	2.66%
	success	20	4.43%

Results

Teacher Fidelity of Participation

The following section provides the breakdown of how much data stemming from each source was collected as a summary of participation and fidelity. First, a total of 13 teachers participated in an exit interview.

There were five professional learning sessions for teachers to attend throughout the program. Including Early Head Start teachers who attended individual professional learning sessions but were not a part of the entire program, 32 teachers attended at least one PL. Out of those 32 teachers, seven teachers attended only one professional learning session, nine teachers attended two professional learning sessions, five teachers attended three professional learning sessions, nine teachers attended four professional learning sessions and two teachers attended all five professional learning sessions.

Excluding the Early Head Start teachers and those who were not included in the larger study, 25 teachers attended at least one professional learning session. Two teachers attended one session, seven teachers attended two sessions, five teachers attended three sessions, nine teachers attended four sessions and two teachers attended five sessions (Table 9).

Table 9. Attendance at Professional Learning (PL) sessions for all participants

# PLs	N teachers
1	2
2	7
3	5
4	9
5	2

Out of the 13 teachers who completed an exit interview, two teachers attended one session, three teachers attended two sessions, one teacher attended three sessions, six teachers attended four sessions and one teacher attended five sessions (Table 10).

Table 10. Attendance at professional learning (PL) sessions for participants who completed an exit interview

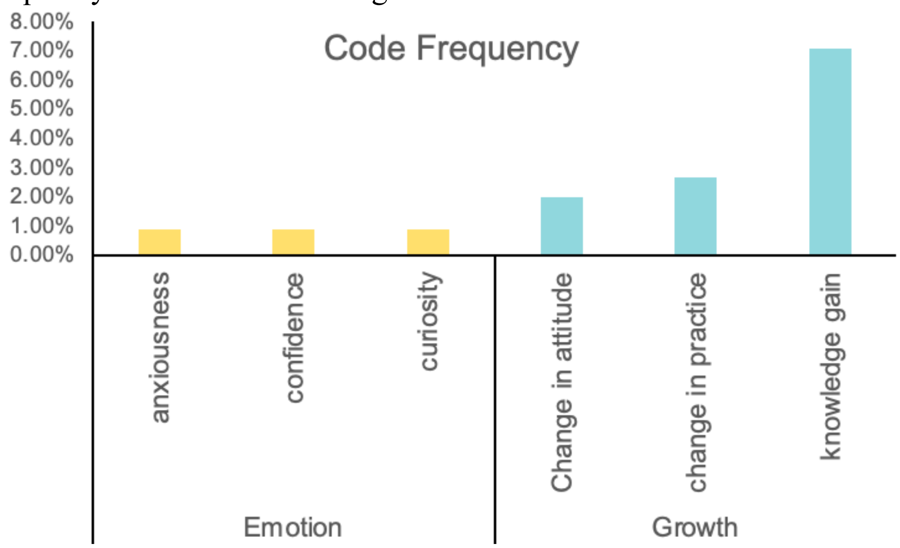
# PLs	N teachers
1	2
2	3
3	1
4	6
5	1

RQ1: How do teachers' attitudes and confidence toward STEM change after participating in the professional development program?

To answer our first research question, we looked into data coded under the larger themes of growth and emotion, to identify any times the teachers mentioned any form of growth or any time they mentioned emotion, as the overarching theme of emotion was used to explore, "how teachers felt about the professional development program, their students, their teaching practice and themselves." and to, "uncover how teacher emotions relate to the professional development program and how their emotions may have changed throughout the program." (Table 4).

Under these two themes, we are specifically interested in the codes of anxiousness, confidence, curiosity, change in attitude, change in practice and knowledge gain (Figure 5). These specific codes are of interest as the data coded under these codes will provide insights into teachers' change in attitudes and confidence toward STEM as well as any changes in their everyday teaching practices due to changes in their attitudes, confidence and knowledge of STEM. From the code frequency of each of these codes, knowledge gain was coded most often among these six codes (Figure 5). This indicates that teachers are identifying specific instances in which they gained knowledge of STEM throughout the program. While this does not directly relate to their attitudes and confidence changing, gaining knowledge in the subject is a precursor to developing the confidence to teach STEM as well as a positive attitude toward STEM.

Figure 5. Code frequency within emotion and growth themes



Delving deeper into the specific quotes shared by teachers through interviews and reflection surveys, we uncover evidence of teachers' specific growth in knowledge, confidence and attitudes toward STEM. We also uncover specific changes in their daily teaching practices as a result of this growth in knowledge, confidence and attitudes. Specifically four teachers' interviews largely focused on their growth throughout the program (Table 11).

Table 11. Teacher quotes under growth theme

Teacher	Summary
Theresa	Theresa attended all five professional learning sessions and participated in an exit interview. She has been with Head Start for about 5 years, and prior was a teacher through Jump Start (https://www.jstart.org/). She shared that working as a Head Start preschool teacher has always been her dream job. Through my interview with Theresa, she shared evidence of her growth as a STEM educator.
Grace	Grace shared that it was her first year with Head Start and began by telling us she,

	“never experienced STEM or any of that good stuff”. She attended four professional learning sessions. Grace shared that when starting the program, she did not know what STEM was. However, from her reflections, we see her newfound appreciation of STEM and for completing this program. She explains that she believes this program gave her new experiences, brought back her inner child, and allowed her to think in new ways.
Aurora	Aurora has been working for Head Start for 16, going on her 17th year. She shared that she just likes working with children overall and that every day is a new experience. She attended four professional learning sessions. Aurora reflected multiple times on the growth in her confidence in teaching STEM and in gaining more knowledge. She also explained that she now recognizes the importance of STEM in preschool and says that STEM can promote problem-solving, and creativity and can challenge students' thinking. She also commented on how completing the program has made her more aware and more purposeful in her STEM teaching.
Aria	Aria has been working at Head Start for about 3 years. She shared it has always been “an aspiration of mine to work for Head Start” and that, “Head Start is a program that has always been, um, looked up to like in this, early childhood field” She attended three professional learning sessions. Aria comments on the growth in her confidence in STEM teaching. She feels like her confidence was boosted, as she was given the skills to teach STEM and now knows what questions to ask. She also reflects on the program being less structured than the normal curriculum they are given and how it can promote problem-solving.

Limited Prior Knowledge

Theresa and Grace specifically commented on their limited prior knowledge and prior classroom teaching of STEM (Table 12). Theresa also mentions that prior to the program, her curriculum and classroom practice focused more on the English aspect than STEM. Theresa shared that prior to participating in the professional development program, she was very limited in her teaching of STEM concepts in the classroom and that her knowledge was limited, the guidelines, standards, and curriculum (DRDP) did not focus on STEM, their lesson plans focused more on math than STEM in general and that overall they focused more on the English aspect of their teaching and curriculum, and believed that this was a more important skill for the students to learn.

Table 12. Teacher quotes under knowledge gain code

Teacher	Quote

Theresa	"I'm like, "What, what do we use as a STEM activity?". I have no [idea]. Since we've been, since we've been doing AIMS, I, I do all that, **but before that, I don't think we did a lot of that.** We didn't do, like I said, **we were more focused on the English aspect**… even on our curriculum guide, there's not a lot of, like our lesson plans are not designed for science, it's designed for math, so we would do math, like um correspondence, but what's important to the DRDP, so we kind of go off that, **so we were kinda limited in our knowledge**… That, that's not very much. It was very limited, so."
Theresa	"We're **always so focused on the English part** and it seems as preschool teachers, **we lack in math and science**"
Theresa	"They're just not as, I could say they're important, but not as important as they need to know their ABC's, and you know how to write, you know, it seems like they're like, oh, the **(STEM) last part of our curriculum.**"
Grace	"**So in the beginning I didn't know what STEM was**… in the beginning, it was just very like, I don't know. To me, it was very foreign, cause, like I said I've never done it before…

Change in Attitude Toward STEM

Theresa, Grace and Aurora comment on specific changes in their attitudes toward STEM teaching (Table 13). They reflect on improvements in their students' behavior and academic performance, as well as an increase in their own enjoyment of teaching. They also mention how STEM activities allow for hands-on learning experiences and introduce new concepts and materials into the classroom. Teachers also appreciate the flexibility of STEM activities. Specifically, Theresa shared that she was able to change her attitude toward what she believed her students were capable of. She specifically reflected on implementing a hopscotch activity in her classroom and her surprise at her students' abilities. Grace shares that she appreciates being able to use different materials, and enjoys STEM teaching. Aurora shares that now that she has more knowledge, she sees it as important. Through these teacher reflections we see evidence of a change in their overall attitudes toward STEM teaching. They display positive attitudes toward STEM as a result of participating in the program.

Table 13. Teacher quotes under change in attitude code

Teacher	Quote
Theresa	"It **(STEM) does awaken that side of your teaching. It improves your teaching,** I think, because then you start to use it like even at large group, you can do a STEM activity. You can do it at small group. You can do it when you're outside. You can, you can do it any time."
Theresa	"AIMS has actually **opened my eyes to it, because I see that they do need that science and math component**…I've seen, um, just a process…that they have this, the math skills seems to be the neglected that, since we've been doing AIMS, I've seen them blossom … And so, um, yeah, I do see it very important. It just seems to stimulate them, and it actually does help with behaviors. It seems like it just, because they're hands-on things, it just seems to stimulate that behavior to subside a little bit, because they're so active in it. Sorry, I don't know, I just, **I just changed my philosophy on, on um the way we conduct those, that area**, so."
Theresa	"I never thought at this age level they could do hopscotch. **I didn't really think that they were capable of doing that**…and **I really was shocked how engaged they were in it**, and every time we go outside we have to take these chalk, cause then they want to draw and make their own hopscotch, you know. And then they want to do the numbers, …so I thought, "**Wow! This is, after not knowing six, seven, and eight, they could do six, seven, and eight and recognize nine and ten**. **So that was a neat, that was neat for me because I really didn't think they were capable of that. I was really shocked. I was just like, "They can do hopscotch?". That's kind of it. It was exciting to see that for me, I really learned a lot from that.** Like, wow, I really didn't think they were able to hop on one foot very well cause their three, you know, and we had a, we had a lot of threes in our class."
Grace	"But then it was kind of like, "Oh, like, I enjoy it," it was like, you know, "**they're telling us something new and something different,**" and it was definitely more enjoyable because it was age appropriate for the children, but then also like for us, like we played games. **It …brought back, like our inner child as, as teachers, you know.**"
Grace	"It was really nice throughout the year to experience … the AIMS meetings, the STEM activities … to be introduced to it… **it kind of makes you think outside the box, too** … the last meeting on Monday, that Miss …she was like, "You know, you don't have to utilize everything that we have here, **you can make something pretty much out of nothing**, but you just have to," I mean, but **without AIMS, we wouldn't really have thought about that**, you know. So it's kinda like …with all the experiences that we went through throughout this year in order to move forward and to utilize, you know, what we have, so that was nice. I really appreciate that for instance."

Grace	"I feel like it's **the STEM is giving them different experiences** that maybe we don't think of within the classroom, you know. Um, it's, it's **building vocabulary**, it's giving them new, kind of like, it's almost like **a new set of eyes without being in the classroom**, you know what I mean? I feel like the **STEM is utilizing items …from everywhere else versus just what we have in the classroom**, so it's also introducing **new materials, new ideas, kind of new concepts**, you know, and building on them"
Aurora	"Um, I was introduced to STEM, uh, you know, two years ago, and I see before I did, I guess I, we were doing it in class, but, you know, I didn't know much of the details. So now that I know, **I have more knowledge about it, I do see it as important**. Um, and now for me, **it has helped me get knowledge and also be more, um, purposeful in my teaching of STEM**

Change in Practice

Grace, Aurora and Aria commented on specific changes in their teaching practices as a result of participating in the professional development program (Table 14). Teachers' comments explain how they are now thinking of things that they may not have had before, such as new supplies and materials to use in the classroom. Teachers reflect that they are now more aware of the related skills that their students are developing through participating in STEM activities. The teachers share that they now are able to guide their students thinking through asking appropriate questions, providing students with different materials, and through now recognizing what skills can come with exploring STEM. These reflections provide evidence that teachers are changing in their practices around STEM activities.

Table 14. Teacher quotes under change in practice code

Teacher	Quote
Grace	"the items and supplies that you give us, and it's like, "**Oh, yeah, I never thought about that**," you know."
Aurora	"I know it does help them a lot, and I can see like, the activities that we, um, have practiced in the classroom, introduced to the children, **it does help them with, you know, the problem-solving**. The, you know, it helps them with, you know, teamwork, working together because that's something that we also try to, you know, teach them in the classroom, um, you know, kind of, you know, share, take turns, play, healthy interactions with children, and that's what kind of STEM

	kind of also with their activities does, um, the problem solving, more, you know, cognitive skills, because um **it helps them more, you know, challenge their thinking.**"
Aria	"you guys have taught us a lot in, um, the simplicity that we can, it's like the simple things that we probably didn't know before being with the AIMS program, and activities that are simple, but they are able to do. Now we do have, like, the math and science part of it that we are kind of like given, but these are more, I would say, I would say they're more fun activities, not as much as, um, like counting cubes, or it's more, that's more structured, you know, and this is more like, not that it doesn't get their wheels turning, but it's more, **I feel like it makes their head think a little bit more, more problem solving**, more "how am I gonna make this happen?", whereas here it's probably more, it's more structured and **I feel like it's more free flow with, um, what we've learned in the STEM and AIMS program"**
Aria	"Um, broadening, like, their way of thinking, their way of thinking by, but it's also us to the questions, **you guys tell us to use the questions that we're using**, um, so it kind of goes hand in hand. **The teacher needs to know kind of more how to, to get them to think into, um, their thought process**."

Confidence Toward STEM

Theresa, Aurora and Aria's reflections display a growth in their confidence toward STEM teaching (Table 15). While the interview questions did not specifically mention confidence, Aurora and Aria identified their confidence as a major area of growth. Teachers mention that they now believe they are strong in STEM teaching, are more confident and more intentional. Along with this newfound confidence, they also have gained knowledge and an understanding of why the activities were important for the students. These quotes provide direct evidence that teachers have gained confidence after participating in the program.

Table 15. Teacher quotes under confidence code

Teacher	Quote
Theresa	"I think it's great for teachers to like open their eyes that we don't have to be so narrow-minded. So, I think it's a wonderful program. I, I wish, I wish I had had that as a kid, because I think I would have liked math and science more, and not,

	not, not, not, not been so, even as a teacher, I'm kind of like weary of it, but now I'm not, you know, now **I'm very strong in it, but I wasn't like that before**"
Aurora	"I enjoyed that we would do the activities first, and then we can teach into them, because then I was more [aware] of, "Okay, this is why we did it". Then with the kids, I'm going to, you know, do it like this. So, um, it has, again, **confidence, confidence, uh, gaining knowledge**, more of, even though before, now I can relate it to how I was teaching before, but now it's more, you know, of the intentional, **really being more intentional as a teacher**. Um, you know, more of the adding, more of the vocabulary, more, just, be more intentional. **It has helped me a lot to be more, as a teacher, be more intentional and more confident. So I really enjoyed being, being part of this STEM training.**"
Aurora	"I think the whole, everything was beneficial to me. **I think I feel more confident, um than before**. Before I was, I needing more of, even though I would do it, you know, I feel like now, I would do some activities, like with science and math, even though we would count daily, and you know, um, but now that I, **STEM has helped me be more aware of that the science, the math, you know, the engineering,** the building has helped me with, you know, um, when I talk to the children, teach the children, have those conversations, um, vocabulary. In my mind, I'm like, "Okay, vocabulary words, open questions, kind of challenging the children to, you know, be more creative, cognitive thinking skills. Uh, so it has made me more, uh, more confident, I feel. **I feel more confident, and when I'm in a class and they're doing these activities, to do more of math**, and, you know, which sometimes it would be a little more, "Oh, my god, what am I going to do?", uh, how to introduce it to children, how to make it fun for them, um keep them engaged. **So, it has made me more, and be more creative**, and now I'm thinking of, "Okay, what activity can I do?". You know, knowing all the activities I've done with STEM, and then I'm like, okay, we did that with STEM, maybe we can do this, so it kind of made me more, me to challenge me, to think also more of the activities, what to do with them, and, but overall, **I think it made me more confident of being more purposeful of, you know, teaching the math, science, and be more creative and more, um, teaching them as much as I can in that area**."
Aria	"**I feel like my confidence in STEM**. It has really, um, even, uh, how Ralph said, like, um, when we had the maker's fair. He thought that everybody was gonna be teamed up with like, uh, a person from the AIMS team, and some of them were out there. But, um, some of them, we just, we, **we already knew what we were doing, and it, it's a confidence boost because we're like, "okay, we know how to teach them how to do this", like, it's, it's just that we needed the tools, and, um, I would say the confidence, too.** You have to build up confidence. It's not easy to, to teach in general is not a natural, um, thing that people have, so to be able to, **our confidence, I feel like was boosted** a lot, like, learning these activities and being able to use even some of the dialogue, you

	guys taught us vocabulary, um, how to boost their vocabulary, it also helped us a lot."

Summary

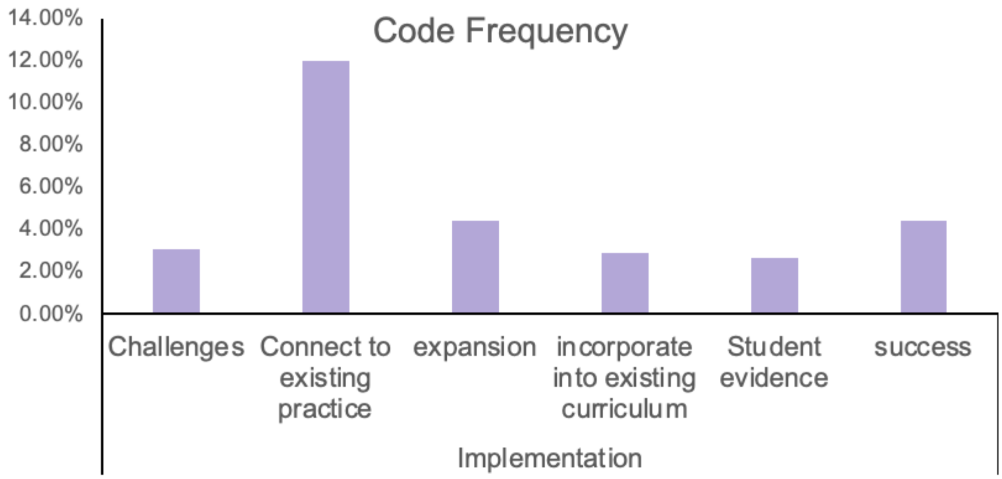
Across these four teachers, we saw evidence of growth in confidence towards STEM teaching, knowledge of STEM, as well as changes in attitudes and teaching philosophy (specifically recognizing the importance of STEM), and recognition of the related skills that children can develop through STEM activities. Teachers gained confidence in STEM teaching and displayed more positive attitudes after the professional development program. One of the teachers, Theresa, shared that prior to the program, she was very limited in her teaching of STEM concepts and that her knowledge was limited. She also shared that the guidelines, standards, and curriculum (DRDP) did not focus on STEM. However, through participating in the program, she identified specific areas of growth within herself and ways in which her attitudes and teaching philosophy changed towards STEM, including a new realization of the importance of STEM education. Grace, a teacher in her first year with Head Start, initially had no experience with STEM. However, after attending four professional learning sessions, she developed a newfound appreciation for STEM and the program. She enjoyed the age-appropriate STEM activities and games that allowed her to think outside the box and brought back her inner child. She also appreciated the new experiences, materials, and concepts that STEM introduced to the classroom, building on the children's vocabulary, and giving them a new perspective on learning. Overall, Grace found the program to be valuable for both the children and the teachers. Aurora reflected on the growth in her confidence in teaching STEM and gaining more knowledge. These gains have made her more intentional and purposeful in her teaching. She recognizes the importance of STEM in promoting problem-solving, and creativity, and challenging students' thinking. Incorporating STEM into her teaching has helped her be more creative and think of more activities to engage children in math and science, and she feels more confident and purposeful in teaching these subjects. Overall, Aurora enjoyed being part of the STEM training and found it beneficial in many ways. Aria's confidence in teaching STEM has grown because of the skills she learned in the sessions. She believes that the program's less structured curriculum promotes problem-solving skills. She says that the sessions have boosted her confidence in teaching and have taught her new vocabulary to improve children's vocabulary. Overall, these four teachers' reflections indicate the success of this program in increasing confidence and positive attitudes toward STEM.

RQ2: In what ways do teachers expand and implement activities presented in the professional development program?

To explore our second research question, we explored all data points coded under the theme of implementation. We looked at responses from all teachers exposed to the program since teachers were able to implement activities even if they attended only one professional learning session. We explore implementation practices, specifically how teachers were able to implement the concepts and vocabulary they learned, and how they expanded different activities.

Within the theme of implementation we are looking into the codes, challenges, connect to existing practice, expansion, incorporate into existing curriculum, student evidence and success. We can see from the code frequency (Figure 6) that connect to existing practice was coded most often within the theme of implementation. This shows that teachers are often making connections from different STEM concepts we have introduced to their current classroom practice and are able to take what we are introducing beyond specific activities and really connect to the concepts. We expand on teacher quotes under the expansion code below. We also group the codes student evidence, connect to existing practice, and incorporate into existing curriculum to explore how teachers expanded their STEM vocabulary usage.

Figure 6. Code frequency within implementation theme



Expansion

During the professional learning sessions, teachers were given time to explore activities and discuss how they would implement them in their classrooms with other teachers. As teachers experienced and practiced different activities during the professional learning sessions, they were also encouraged to implement the activities in whichever ways fit their classroom best, with encouragement to adapt the activities. One teacher discussed how she appreciated the time during the professional learning sessions to discuss how she could expand activities with her co-teachers.

> " I think, like, having the Aims teachers and mentors there to actually guide us through the activities and show us really a positive and something that I really enjoyed. And like I said, **we got to ask each other, our other teachers, co-teachers, teachers that were there, as well as our teams members, ask them questions, okay, what could we add? Or how would this work?** Or I think even one of the teachers said we could even use recyclables for one of the activities. That was, I think, tubes and tunnels. And she ended up bringing stuff from her own house. But, yeah, I think just really having to practice the actual activity with other co-teachers. And Aims team members really help because we get that feedback one on one, and like I said, **we get to ask questions and actually practice the activity.**"

Another teacher expanded the setup of the hopscotch activity. This teacher expanded this activity and incorporated measurement.

> Well, **I took it in another step, and I had the kids help me draw it**. So, they got to, they got to, we got to look around the classroom and look for an item in the classroom that we could use to trace the squares that was about the same size to fit their feet and my feet, and so we found a puzzle. So, it, **it involved measurement** because they had to use, um, not so much a measuring device, but they had to, basically, they would grab items, and they would have me lift my foot, or they would put it next to my foot, and then they would put it next to their foot, and they, so I made it an activity for them

Another teacher implemented the Hex Bug activity in a new way than she usually does, allowing the children to truly explore the activity and construct their own mazes, rather than having them already constructed.

> **I just put the materials out, and I just left them there. Instead of having them make a maze, I had them do their own maze**. I had them, I just left them there, and said, "How are we going to do this?", you know, **instead of constructing it for them**, and so then I would, you know, we had like four or five, and they were like, "Well, we could do this, and we could," it was like, it just stimulated their brain to figure out, "Well, Miss," and then, they didn't like, they didn't know what to do with the tunnels, and I said, "Well," and then I looked, a little girl came up, "We can do races with those tunnels, with the hexbugs," you know, and, and so that was interesting. She came up with that, and then one, so we could make a maze on top of the tunnel, and, um, we can see if the hexbugs can go through. So, um, for me, that was probably, that was, because usually we put out the materials and we create the maze for them, and I know, I, I wanted to see if they could do, do it on their own, and what they would do with it, how they could explore with it, and they really took off, and I'm telling you that was probably, they sat there for almost 40 minutes [inaudible; "do the map"?], just, I mean, I had all of them around. They were actually sharing and kind to each other, not biting, taking turns, racing, and we only had five hexbugs. I had 12 students that day, but they were taking turns as teams. They even paired themselves up in teams, like, "Who's going to be three, who's going to be with this group?", and then, you know**. So that was kind of interesting how that worked, but that was a wonderful, um, I thought that was a wonderful way of adapting that, because, like I said, we really construct everything and put it together**.

Another teacher expanded the game of hopscotch and included some aspects of computational thinking; namely creating an algorithm for her students to follow, with specific directions for each square they landed on.

> “Now, what I did to change it was inside, because it was very early, and we weren’t prepared to go outside. What we did inside was **we had little squares that give you like a gesture**. Either hop, um, squat, uh, balance. So what I did with those is I used the squares, and I kind of made it in that same generalized shape, I guess you can say, as the hopscotch, and so every time they would, like this one would say, “Hop”, so you hop to the next one. When you get to that square, you would balance. The next square, you would, um, squat or bend over. There was just different gestures that they did”

Overall, we saw evidence of teachers expanding the activities presented in the professional learning sessions by incorporating other STEM concepts into the activities. Teachers expanded activities by including measurement concepts, computational thinking, and algorithmic thinking, and letting children explore the activities without specific teacher instructions. Teachers also appreciated the time they had during the professional learning sessions to discuss how to implement and expand activities with their fellow teachers.

Vocabulary: *Student Evidence, Connect to Existing Practice & Incorporate into Existing Curriculum*

When introducing teachers to STEM concepts and activities, one of our goals was to have teachers recognize how this new information fits into their existing practice. One of the main ways in which teachers connected what they learned in the professional learning sessions to their current classroom practice, was by expanding the vocabulary they used daily with children. Teachers mostly commented on their increased awareness of using more challenging and STEM-focused vocabulary with their children. Below are seven quotes from six different teachers explaining their novel use of STEM vocabulary.

> “but it also gets, **it lets them express and learn those, the vocabulary**. Um, like something simple as, um, a bean bag song, you know, telling them to put the bean bag over their head, to put it up high, put it down low. **The vocabulary, up and down, um, children, you know, unless they hear it all the time, they're not understanding**, but things like balance, and, uh, you know speed, and then measurements, unless their parents talk to them and interact with them at home, um, using things around the house like you know building materials or cooking materials. It's not something that you hear every day, so I think in preschool **if we can introduce them, it gives them a step up and opens their eyes**, and I mean, honestly, **it's building young little engineers and people, you know, that are wanting to experiment and challenge things**”

"While they line up to go outside and back inside. We implement **spatial relationships** all the time on free choice while building with blocks, they create their own structures and throughout the day."

"STEM has helped me be more aware of that the science, the math, you know, the engineering, the building has helped me with, you know, um, when I talk to the children, teach the children, **have those conversations**, um, vocabulary. In my mind, I'm like, "**Okay, vocabulary words, open questions, kind of challenging the children to, you know, be more creative, cognitive thinking skills**."

"**I really liked the positional, um, the one using positional words as far as uh incorporating it, incorporating it into our music and movement**. And I think uh my co-teacher, um, Ms. Flores, ended up doing um yoga with it."

"Well, when we did like STEM activities, it was like, we would do magnets, and, but it would be like we would not go further with, "Okay, this is a magnet", **we wouldn't go further with the vocabulary**. We wouldn't stimulate them, that, "Oh, is this vibrating?", "Is this", you know, it was, like, really short words like three letter words. It was no like five, six, you know, vocabulary words, and um as **a preschool teacher, you think you're overstimulating, but actually, they catch on very quickly,** like vibration. I was able to use vibration when I was doing the hex bugs, and that is a pretty big word, and you have to explain that word, [inaudible] or what that means. And so children were like, "Well, that means it tickles". I say, "Yeah, it's part of tickling", but you know, you know. So it's kind of, um, **it's a neat aspect that you get into the vocabulary**"

"even like when we're lining when we're walking to the classroom, I would tell the kids, "walk **beside me** or **in front of me** so I can see you, if you walk **behind me** I can't see you", and they're not sure, they're still walking behind me. I go, "no like **beside, like right here, or in front**, you're walking in front of me". So they're still learning the vocabulary, um, so it's, it's a little bit difficult, but I mean they eventually get it."

"Just how you guys like would give us the, the "**who?", "what?", "when?"**, those questions, we also have those questions, like, in the classroom, um, in different parts of the classroom, just to further get their thinking and to tell us you know, **"how did you make it?**", uh, when, um, "**how did you come to this?**", uh, "what, **what were the steps?", "what, what did you do first**?", so more of, it's **a lot of question asking**, and also just seeing them, how they, they process what we were telling them to do."

Teachers incorporated concepts from the professional development program into their classrooms mainly by incorporating more STEM vocabulary. Teachers showed an increased awareness of using more challenging and STEM-focused vocabulary with children as one of the main ways they connected what they learned to their current classroom practice. They found ways to add STEM vocabulary to activities they were already using in their regular practice. The teachers reported using STEM vocabulary in various ways, such as during music and movement activities, lining up for class, and building with blocks. They also found that questioning children about their STEM activities further enhanced their thinking and problem-solving skills.

Discussion

The first goal of this study was to identify changes in teachers' attitudes and confidence toward STEM teaching. We qualitatively analyzed 13 interviews and 90 reflection surveys, each containing four questions, to answer each of our research questions. We explored larger themes of emotion and growth, to identify specific areas of growth and changes in their emotions within the teachers. Specifically, we looked at data codes as, changes in attitude, change in practice, knowledge gain, curiosity, anxiousness, and confidence. The results displayed that the teachers were limited in their teaching of STEM concepts before the program, their knowledge was limited and their standards, and curriculum (DRDP) did not focus on STEM. Prior research has shown there is little evidence reporting professional development programs that have been able to significantly change instructional practices (Lieber et al., 2009). However, we identified specific changes in teachers' attitudes and practices. Results showed that the teachers changed in their attitudes toward STEM teaching and changes in their teaching philosophy. Teachers displayed more positive attitudes toward STEM. The teachers became aware of the importance of STEM in early childhood education. They also recognized that teaching STEM can improve their teaching abilities and positively impact student behavior. The teachers developed new teaching approaches and strategies that helped their students grow in areas that they previously believed were not possible. Most importantly, the teachers developed the confidence and were given the materials to implement these activities and to teach these concepts in their classroom. These findings provide insights into some of the ways teachers may gain confidence, change attitudes and practices through professional development participation. In future work, we plan to investigate the specific aspects of this professional development which led to these changes and what makes a specific professional development effective.

The second goal of this study was to explore the ways in which teachers were able to implement and expand the STEM activities presented in professional development. We explored the theme of implementation, and codes, expansion, success, student evidence, incorporate into existing curriculum and connect to existing practice, to identify ways in which teachers implemented and expanded activities and concepts presented in the program. Results show that teachers expanded the activities to fit their classroom needs. For example, one teacher incorporated measurement into the hopscotch activity, another teacher allowed the children to construct their own mazes in the Hex Bug activity, and a third teacher included aspects of computational thinking in the game of hopscotch. Teachers also incorporated concepts from the professional development program into their current teaching practice and curriculum. The teachers mostly commented on their increased awareness of using more challenging and STEM-focused vocabulary with their children, which helped to build cognitive thinking skills and vocabulary. We present evidence from several teachers explaining how they integrated STEM vocabulary into their existing practice, such as during free choice time, music, and movement, and lining up for activities. The teachers also discussed the use of open-ended questions to further stimulate their students' thinking and to encourage them to explain their thought processes. One of the factors which makes up an effective professional development program is that the teachers should be an active part of the program (Siegel & Giamellaro, 2021). Through active participation our teachers were able to explore the activities themselves and practice implementation and brainstorm questions they would ask and discuss how they would implement activities with their co-teachers. Overall, we were able to see teachers expand on the concepts presented in the professional development program and apply the concepts to their current classroom practice.

Implications for professional development

This study provides important implications for the design and implementation of professional development programs with early childhood educators. Two factors that makes an effective professional development program is that the program provides opportunities to increase teachers' confidence and improve attitudes toward STEM (Hamre et al., 2017) and to monitor for effectiveness (Gomez et al., 2015). It is important to be aware of teachers' attitudes and practices regarding STEM education at the beginning of a program and important to record how their perceptions develop and change throughout their participation in professional development programs. Teachers and their viewpoints are an active and important aspect of the professional development program and should be taken into consideration in the design and implementation of professional development programs. Further, data was collected throughout the program and used to make iterative changes in each of the modules. Feedback throughout a longer-term program can help to make the program more effective. Data collected, including themes around barriers and activity feedback will be explored further in the future to provide additional recommendations on the design of professional development programs and barriers in place that may limit participation and implementation.

Implications for Preschool Classrooms

This study shows important implications for how to develop confidence in STEM teaching in early childhood teachers. Developing this confidence and positive attitudes toward STEM teaching will potentially impact future preschool students. Specifically, students' experiences in STEM in preschool have been shown to indicate later success (Duncan et al., 2007; Nguyen et al., 2016). By integrating STEM into their experiences, through training teachers, we are exposing children to high-quality early childhood education which is related to later cognitive and academic outcomes and may be especially important to children at risk (Campbell et al., 2002; Reynolds et al., 2002). Further, by training teachers to implement these activities and changing their outlook on STEM education, rather than implementing activities directly with one cohort of children, we have the ability to reach future cohorts of children, as these teachers teach new children each year. Further, evidence indicates that teachers' instruction is a strong factor in promoting children's active involvement in learning (Hamre & Pianta, 2005; Lieber et al., 2009). By training teachers and changing their practices and attitudes, we hope to increase children's involvement in STEM learning specifically. Future work will include student data to explore impacts on students. While there is little evidence reporting effective professional development programs that have been able to significantly change instructional practices (Lieber et al., 2009), we identified specific changes in teachers' practices and attitudes regarding STEM.

Limitations

While we explored the themes of emotion, growth, and implementation for this study, the themes of barriers and activity feedback were not explored. These themes can provide us with important information about the barriers which early childhood teachers, students, and families face in their access to and participation in STEM training and learning. Information about teachers' feedback on the specific activities used in the professional development program can also provide us with important implications for the design and implementation of effective and engaging professional development programs. These two themes will be investigated in future studies. We plan to explore questions such as, 1) What barriers exist to successful professional development programs? 2) What makes a successful professional development program? We plan to conduct analyses and write papers on barriers to STEM teaching and learning and to professional development participation and the design of effective professional development programs.

The main limitation of this study is teacher participation. While 26 teachers were exposed to the program in some aspect, only two teachers were able to attend all five professional learning sessions and only one of those teachers also completed an exit interview. Only half of the teachers completed an exit interview, limiting our conclusions to those teachers who completed the exit interview. Therefore, we are unable to get a complete picture of the effects of the program. Our measures of participation are also flawed, in that we measured participation in terms of who completed and turned in a reflection survey. However, some teachers did not include their names, and some may have left the professional learning session before completing the survey. Future design of professional development programs could explore how to increase participation and more accurately measure participation.

Another limitation is that we did not collect any data regarding the students who may have benefitted from this program. To truly measure the program's impacts and the ultimate goal of improving students' access to STEM, it is important to collect student data. However, we were unable to collect student data for this iteration of the professional development program. Future plans include collecting student-level data.

Another limitation was in the collection of the coaching logs during the professional development program. We did not set forth any guidelines for coaching logs and for coaches to fill them out. We ended up receiving a wide range of detail and participation in the coaching logs and did not include them in the data analysis due to their inconsistencies. However, in conducting the professional development for the 2022-2023 school year, we created a uniform coaching log report system with specific guidelines, which should lead to more uniform data collection.

Future Directions of the Program & Partnership

We plan to continue delving into the qualitative data surrounding this professional development program. Specifically, we plan to investigate the barriers teachers, students, and families face in regard to STEM education. We also plan to investigate the design of an effective professional development program and the design of engaging activities by looking into teacher feedback on the activities.

The Head Start partnership is continuing for the 2022-2023 school year (Figure 7). We are currently running another six-month professional development program with teachers. However, the program this time has a focus on computational thinking and programming with the use of a robot. Some of the teachers completing the program this year also participated in the program for the 2021-2022 school year, which this study is written about. However, there are also some new teachers. We are collecting data in the form of teacher reflections, coaching logs, and interviews. We plan to analyze data in a similar manner as in this study. However, the continuation of the partnership also allows us to investigate the long-term impacts of the multi-year partnership on students and teachers.

Figure 7. Summary of Future Directions of Partnership from Head Start Partnership Annual Report (2021-2022) https://aimscenter.org/pk12-partnerships

Conclusions

The larger project, where this study was situated, aimed to 1) continue a research-practice partnership with a local Head Start center, and 2) examine the benefits of the program for teachers. The research-practice partnership was strengthened by conducting this professional development program, and the partnership will continue for the 2022-2023 school year with another 6-month professional development program. Further, the partnership is expanding to other Head Start sites for the 2023-2024 school year. My role within the partnership is also continuing, as I continue to work with the team to design effective and engaging professional development training and activities, collect teacher data on their experience during the program, and analyze this data to examine the outcomes of the program and partnership. I was also able to examine the benefits of participating in this program for teachers, identifying specific areas of growth in their confidence and teaching practices and philosophy.

The broader goals of the larger professional development project and research practice partnership were to 1) increase access to STEM education experiences in early childhood, 2) increase early childhood teachers' confidence attitudes towards STEM teaching and learning, and 3) provide quality professional development opportunities to Head Start professionals. We were able to provide new STEM activities for teachers to use in their classroom, and therefore provide early childhood students with STEM education experiences. We also saw evidence of early childhood teachers' confidence toward STEM increasing through exploring the themes of growth and emotion throughout teachers' reflections and interviews. Further, teachers were provided with quality professional development sessions (Figure 8). We will explore the themes of teacher feedback in another study, to further explore this goal of the larger project.

Figure 8. Summary of Partnership Outcomes from the Head Start Partnership Annual Report (2021-2022) https://aimscenter.org/pk12-partnerships

2021-22 OUTCOMES

WHAT IMPACTS HAVE HEAD START STAFF EXPERIENCED?

- → **Increased confidence as STEM learners and teachers.**
- → **More variety of classroom STEM activities.**
- → **Fostered home and community connections.**
- → **Applied personal learnings to improve teaching.**

TEACHER REFLECTIONS →

Teachers create a paper chain to reflect on their learning during the year.

Q: What was most valuable about the project?

A: The time you spent explaining it to us, and not just giving us a to do list. So like getting to fully experience the whole aspect of the activity, the hands-on, like us doing it.

Q: What have you learned through this project?

A: I learned a lot because we don't know as adults how the minds of children are, and that taught us we have to step back and we have to think and know how we would word things to make it easier for a child to understand at their level.

Q: How have you changed as a teacher?

A: I think as a teacher I would go through the motions, and we're doing it, and we're hoping they get the concept. But once we understand what we're doing and why we're doing it, it makes it a lot easier for the kids to get it because we're not just doing it like robots.

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Overall, this program was successful in reaching the overall project goals and specific study goals. The first project goal was to increase access to STEM education experiences in early childhood. Teachers were able to successfully implement activities presented to them in the professional development program. Children were then exposed to new STEM education experiences. The second goal was to increase early childhood teachers' confidence in attitudes toward STEM teaching and learning. This growth was illustrated through teacher reflections and interviews where they shared growth in their confidence toward STEM teaching and changes in their attitudes and practice. The third goal was to provide quality professional development opportunities to Head Start professionals. We successfully led and completed this 6-month program with teachers. All three main project goals were reached.

We identified changes in teachers' attitudes and confidence toward STEM by analyzing teacher reflections and interviews, finding evidence that teachers did grow in their confidence in STEM teaching and increased positive attitudes towards STEM. We also identified the ways in which teachers implemented and expanded on concepts and activities presented in the program.

Acknowledgments

I would like to thank the AIMS team for all of their hard work and dedication to making the world a more STEM-friendly place. I have found great support and friendship from the AIMS team and truly appreciate all of their hard work and the differences they make in the lives of so many children and teachers. I would also like to thank Madison Berube for spending numerous hours coding data and for being someone I looked forward to frequently meeting with to discuss data analysis and for being such a supportive team member. I would also like to thank all of the Head Start teachers, students, and families

for embracing a new challenge in tackling STEM learning and welcoming us into their community. It was a pleasure working with everyone and seeing the children grow and become excited about STEM!

ACKNOWLEDGEMENTS

The success of this partnership is due to the hard work and dedication of many people. We would like to acknowledge and thank the following individuals and groups for their willingness to grow, adapt, and thrive as they serve the children of this Head Start community:

Franklin and Early Head Start's dedicated staff
of teachers, teacher assistants, and support team. Their daily commitment to providing innovative, quality learning experiences for students is commendable.

Rosa Pineda, Helen Uyeda, Aletria Snowden & Ralph Carrillo
whose leadership helps provide the resources and avenues necessary for innovative teaching and learning.

Franklin and Early Head Start families
including all parents, care-givers and children. They have been wonderful in implementing take-home kits, providing feedback, carrying classroom learning into their homes, and overall being the heart and soul of this partnership.

The AIMS Center for Math and Science Education team
of leaders, coordinators, and support staff, including our Research Fellow Hannah Smith.

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What I learned

I have participated in the design, implementation, and evaluation of this project over the past year. Participation in this project has allowed me to grow as a researcher, student, and employee. I was able to experience working outside of an academic setting, working with a team at a nonprofit center outside my normal geographic area. I also gained experience in designing and implementing a large professional development program reaching early childhood educators. I worked with a different population and group dynamic than before and experienced the challenges of working in a real-world setting, beyond lab experiments, while working with a research-practice partnership. I also trained a research assistant in qualitative data analysis and learned a new program for qualitative analysis. From this experience I have come to appreciate the value in research practice partnerships, both personally, in research, and for the practice partner. Personally, it is extremely rewarding to see the direct impacts of research on students and teachers and to be able to collaborate with learners and educators and see things from different perspectives. I believe it is vital that researchers step out of the research lab and into the everyday world of the populations they study to keep perspectives fresh and understand the true ultimate goals of their research, as well as be able to design implementations around the actual needs of communities they serve, rather than be propelled by the goals of research. In research, the value of research practice partnerships are innumerable. Partnerships provide opportunities to explore long term impacts of implementations and to uncover real-world barriers that we are unable to detect in controlled laboratory studies. They provide opportunities to explore actual implementation of research and the difficulties that come with this implementation into the real world, beyond a computer screen or laboratory. Finally, for the practice partner, these partnerships provide a link to novel research that they can directly implement. This link is important, as publications do not always get into the hands of teachers or students, and often take years to publish. With these partnerships teachers and students are able to access research outcomes faster and in an easier manner to provide a greater impact on learning.

I have also learned the value of transforming research outcomes into applicable curriculum for teachers to use. If we keep our research behind the walls of the ivory towers of the world, our research will be limited in its real impact, far beyond whatever impact factor a journal may admit to having.

Finally, I have learned to appreciate the different insights provided by both quantitative and qualitative data. I appreciate the clear outcomes provided by quantitative data on learning and improvement. However, I have grown to appreciate the rich detail provided by qualitative data, giving us a deeper look into the development, thoughts and growth of participants. I am excited to continue exploring the qualitative data from this project, as well as other projects in my future. As I continue on as a researcher, I plan to try and include both qualitative and quantitative measures as I design future studies to provide deeper and fuller pictures of the impacts of my work.

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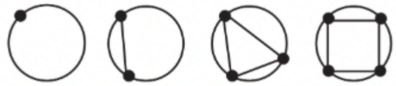
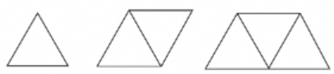
Appendix A Patterns

NOW WHAT?

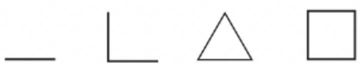
Discover the patterns and fill in the blanks.

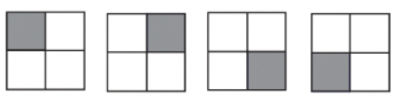
1.  ________

2.  ________

3.  ________

4.  ________

5.  ________

6.  ________

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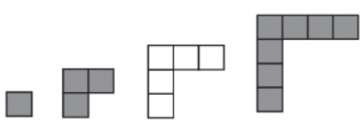
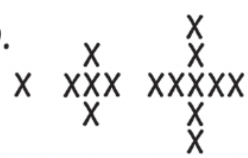
8.  ________

9.  ________

10.  ________

Make up some patterns of your own.

aims CENTER

PICKING OUT PATTERNS

GRADES PK+

MATERIALS

bag for gathering sticks • bag for gathering leaves • Dance Code cards

OBSERVE

Allow children to explore their environment and go on a scavenger hunt for sticks and leaves. What other items do you have around you that could be used to make a pattern?

CREATE

Scan the QR code or visit www.youtube.com/aimsed and search "Picking Out Patterns" to watch the instructional video to create visual patterns from items collected on a scavenger hunt. Create a pattern and ask your child to repeat the pattern. Then, ask your child create a pattern for you to repeat.

PLAY

After creating patterns, use the Dance Code cards to attach a movement to each item in your pattern. Then, dance to your pattern! Items can also represent sounds, shapes, or other actions. Be creative!

KEY CONCEPTS

Operations/Algebraic Thinking
Child understands simple patterns

Symbolic Representation
Child uses objects or symbols to represent something else.

Creativity
Child recognizes differences between familiar and unfamiliar objects or actions.

QUESTIONS TO ASK

- What patterns do you see?
- Can you continue the pattern?
- What other items can we find around us to create patterns?
- How many items/movements are in your pattern?
- Can you describe your pattern?

THINGS TO NOTICE

- Child's excitement as they dance to their pattern
- Child's interest in objects, sounds, and movements
- How the child attempts to repeat a pattern
- Creativity of your child's patterns

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DANCING PATTERNS

GRADES PK+

MATERIALS

movement spinner • movement cards

OBSERVE

Allow children to try out the movements on the cards. Spin the spinner and have fun doing the movements that the arrow points to.

CREATE

Scan the QR code or go to www.youtube.com/aimsed and search "Dancing Patterns" to watch the instructional video to create a dance with the spinner and movement cards. Spin to choose a movement and find the card that matches. Spin two more times and add each card in a row. Repeat the pattern.

PLAY

After creating a pattern of movements with the spinner and cards, dance to your pattern. Enjoy adding music or coming up with different dance patterns. What other movements could you use?

KEY CONCEPTS

Operations: Algebraic Thinking
Child understands simple patterns

Symbolic Representation
Child uses objects or symbols to represent something else.

Creativity
Child uses imagination in play and interaction with others

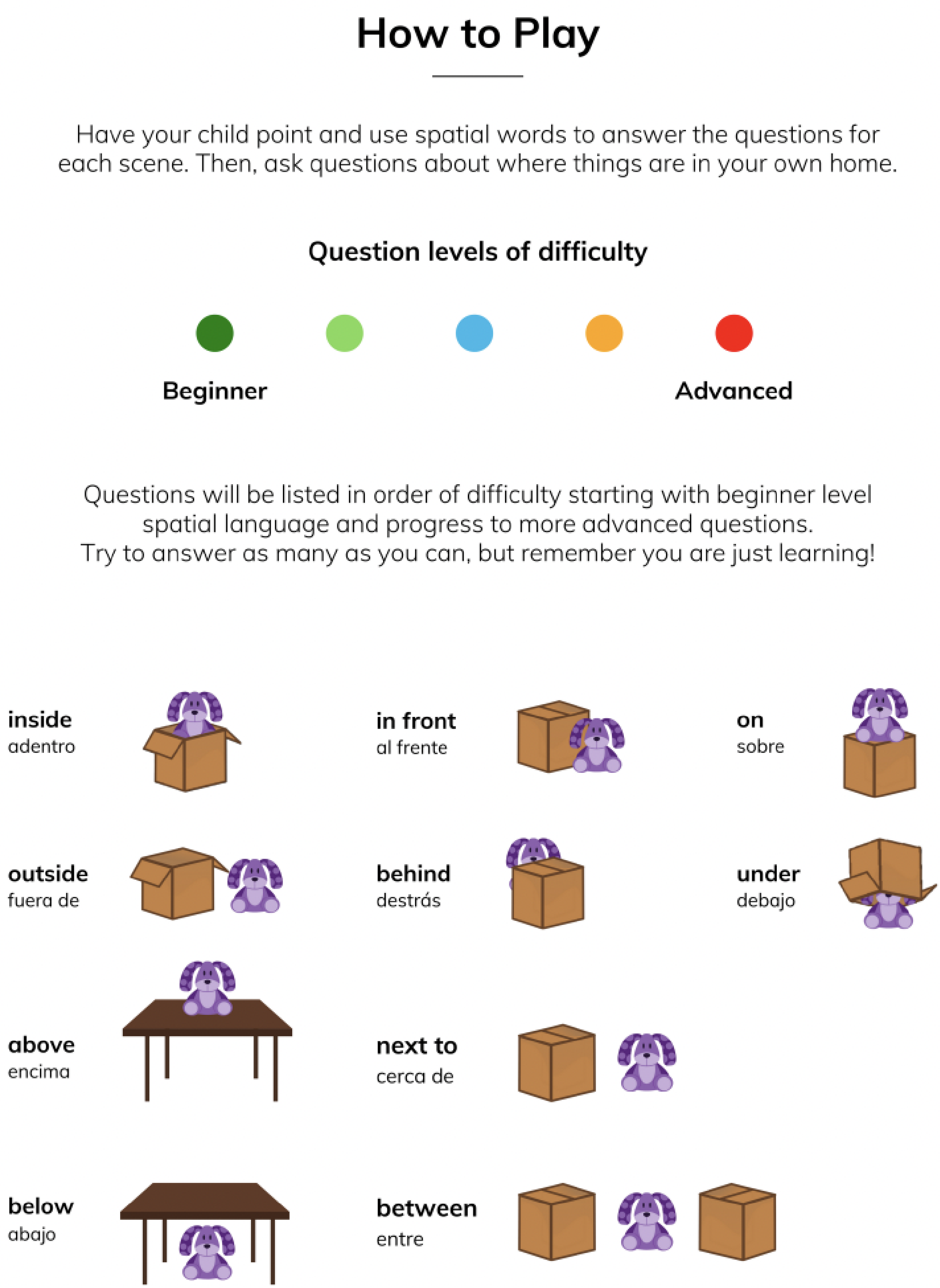
QUESTIONS TO ASK

- What patterns do you notice in dances that you know?
- How fast/slow can you go?
- What sounds do you hear in our dance pattern?
- How many times do you want to repeat the pattern?
- How could you record your dance?

THINGS TO NOTICE

- Child's joy as they dance
- Child's creativity
- How does your child figure out what comes next?
- How does moving help your child to remember the pattern?

Appendix B Spatial Communication



In the playroom...

- Where is the bunny?
- Where is the rug?
- What is on the wall?
- What is on top of the table?
- What is in front of the box?

En la sala de juegos...

- ¿Dónde está el conejito?
- ¿Dónde está la alfombra?
- ¿Qué hay en la pared?
- ¿Qué hay encima de la mesa?
- ¿Qué hay delante de la caja?

At the park...

- Where are the apples?
- What is in the sandbox?
- What is next to the tree?
- What is under the slide?
- What is on top of the bench?

En el parque......

- ¿Dónde están las manzanas?
- ¿Qué hay en la caja de arena?
- ¿Qué hay al lado del árbol?
- ¿Qué hay debajo del tobogán?
- ¿Qué hay encima del banco?

Bev's Team: Send Scott from the *Gate* to the *Office!*

Directions for Scott

Exit off the grass

Walk to the black top

Follow the chain

Skip 5 times forward

Run forward 30 sec

Stop running

10 hops forward

4

Bev's Team: Send Scott from the *His Truck* to the *Playground!*

Directions for Scott

10 steps forward

Turn left 90 degrees

Walk forward until you pass the cars

Turn right 90 degrees

Skip until you touch the fence with your hand

Turn left 90 degrees

Follow the fence until there is an opening for the fence

Walk through the opening

Make a right turn

Follow the fence

8

Now try to give directions to Scott without using the following words....

Straight	**Follow**	**Between**
Across	**Over**	**Inside**
Around	**Left**	**Down**
Through	**On**	
Out	**Towards**	
Forward	**Right**	

11

Bev's Team: Send Scott from the *Playground* to the *Cafeteria!*

Words to avoid.... Straight, Across, Around, Through, Out, Forward, Follow, Over, Left, On, Towards , Right, Between, Inside Down
Walk ahead until he gets to the chains by the grass area Turn your body to face the building that says office Walk until you can touch the building that says office and stop Rotate until you face the double green doors Walk until you can touch the double green doors Open the doors and walk inside the auditorium Walk ahead five paces and turn opposite of the windows to see the cafeteria. Walk until you reach the cafeteria and stop

13

https://youtu.be/Uolt1A78lBE
https://youtu.be/8RPHzceNdAY


20
Xx

Appendix C Movement

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FEED THE MONSTER

AGES 0-5

MATERIALS

- Monster face template & stickers
- Paper bag for Monster
- Monster food & feeding bag
- Movement cards
- Foam dice

OBSERVE

Allow children to explore the dice and movement cards. Let them roll the dice and try some of the movements.

CREATE

Scan the QR code or visit bit.ly/make-your-monster-video to watch the instructional video to create and decorate their monster.

PLAY

After creating the monster, roll the dice to see how many pieces of food the monster wants to eat. Have fun using the movements on the movement cards to get to your monster or away from the monster. What other movements can you make?

KEY CONCEPTS

Spatial Relationships
Children will explore their body in space as well as the monster's place in space.

Perceptual Motor Skills and Movement Concepts
Child coordinates large and small movements.

Creativity
Child shows imagination in play and interactions with others.

QUESTIONS TO ASK

- What movements can you use to get to or away from your monster?
- How many pieces of food did your monster eat?
- What sounds does your monster make?
- How many movements do you think it will take to get to your monster?

THINGS TO NOTICE

- Child's movement towards or away from the monster.
- Child's creativity and imagination.
- How the child counts movements or pieces of food.
- How the child does the movements on the movement cards.


cuties


Don't Doubt,


NEW!


LUNGE

INTERACTIVE YOGA

AGES 0-5

MATERIALS

- Yoga cards
- Small soft doll or animal
- Optional: Relaxing music

OBSERVE

Allow children to look through the yoga cards. Talk about where the animal is and what the pose looks like.

CREATE

Scan the QR code or visit bit.ly/interactive-yoga-video to watch the instructional video.

Put on some relaxing music and use your body and animal to make the yoga poses from the interactive cards. Hold the pose while counting 1, 2, 3, 4, 5.

PLAY

What other ways can you move your body?
Where might you put your animal?

KEY CONCEPTS

Spatial Relationships
Children will explore their body in space as well as the small animal's place in space.

Perceptual Motor Skills and Movement Concepts
Child coordinates large and small movements.

Visual and Performing Arts: Dance
Child explores different ways to move their body.

QUESTIONS TO ASK

- Are you making the same shape as the picture?
- What is your favorite pose?
- Where is the animal or doll?
- What body part is getting tired?
- How should we move our body next?
- Where should we put the animal or doll?

THINGS TO NOTICE

- Child's ability to match the pose.
- Child's ability to use spatial language. (under/above, next to/near, etc.)
- What child pays attention to on the card (animal placement, body position, etc.)
- Child's ability to move into and out of different poses

WIDE LEG FOLD

Put the animal in between your legs.

Pon al animal entre tus piernas.

FORWARD FOLD

Put the animal on top of your feet.

Pon el animal encima de tus pies.

CRESCENT LUNGE

Hold the animal above your head.

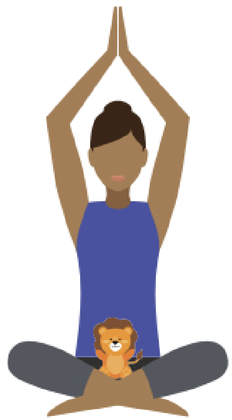
Sostén al animal sobre tu cabeza.

DOWNWARD DOG

Put the animal below your body.

Pon el animal debajo de tu cuerpo.

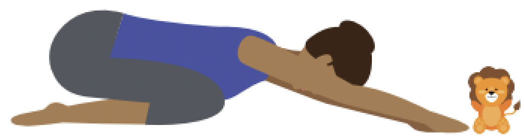
LOTUS



Put the animal inside your lap.

Pon el animal dentro de tu regazo.

HALF TORTOISE



Put the animal in front of your hands.

Pon el animal delante de tus manos.

CAT POSE

Put the animal on top of your back.

Pon al animal encima de tu espalda.

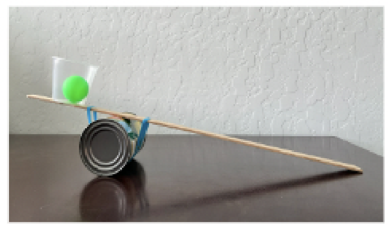
QUESTIONS TO ASK

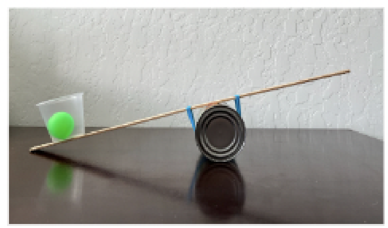
- What is your goal? (distance, height, speed, or accuracy)
- What worked well? What didn't work well? Why?
- How can you measure the distance the object traveled?
- Where do I want to put the cylinder?
- How did the ball fly?
- What else might fly well from the catapult?

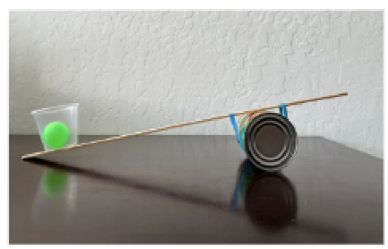
PLAY

After building the catapult have children use the catapult to launch the ball.

→ Adjust how hard you hit the paint stirrer.
→ Adjust the placement of the cup.
→ Adjust the location of the cylinder







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TINKERING WITH A CATAPULT

AGES 1-5

MATERIALS

- Cup
- Large paint stirrer
- Large rubber band
- Ping pong ball
- Sticky dot or tape
- Strong cylinder : can, water bottle, etc.

KEY CONCEPTS

Geometry & Spatial Sense
Try different ideas and experience what happens.

Plan and Carry Out Investigations
Explore structure and functions as you build and adjust your catapults.

Measurement
Use non-standard (steps, blocks, etc.) or standard (measuring stick, measuring tape, etc.) tools to measure the distance/height.

THINGS TO NOTICE

- Children's curiosity related to the catapult.
- How the child adjusts the catapult.
- How the child measures their achievement of the goal. (distance, height, speed, or accuracy)
- Vocabulary they use to describe what happened.

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OBSERVE

Explain the goal and allow children to explore the material you give them to design and build a catapult.

CREATE

STEP 1. Attach the cup to the paint stirrer using tape or a sticky dot. Press down and hold for 5 seconds.

STEP 2. Loop a large rubber band around one end of the paint stirrer. Then, wrap the rubber band under the cylinder, then back around the paint stirrer on the other side.
*Tip: It is easiest to do this at the ends of the paint stirrer, then slide the cylinder towards to the center once completed.

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EMBODIED FROG SPLASH

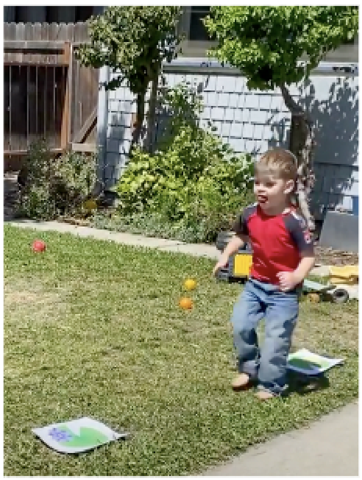
AGES 0-5

MATERIALS

- Lily pads
- Frog headbands

OBSERVE

Allow the child to explore the material. What are they curious about? How do they want to play with the material? Allow their creativity to drive the play.



CREATE

Create a scene for them to become the frog and bounce from lily pad to lily pad. Tape the lily pad to the wall or place it on the floor. Encourage the child to be creative about how they can move as a frog. Do they want to swim, hop, etc? Then have them count how many moves it takes to get to the pond.

PLAY

Have fun leaping, swimming, and counting! Lily pads can be moved and the game can be changed in many ways. Count together as the child makes their moves.

KEY CONCEPTS

Counting & Cardinality
Child knows number names and the count sequence. Child recognizes the number of objects in a small set. Child compares numbers.

Geometry & Spatial Sense
Child explores the positions of objects in space.

Symbolic Representation & Play
Child uses objects or symbols to represent something else.

QUESTIONS TO ASK

- What do you want to know about frogs?
- How does a frog move?
- Which color lily pad do you want to go next?
- How many lily pads are there?
- What does the frog want to do next?

THINGS TO NOTICE

- Child's creativity with the pretend play.
- Child's large motor movement.
- How high can the child count.

Peregrina El Salvador

Directions:

1. Toss the bean bag into the first box.
2. Hop over the first box and into the second box.
3. You must not put your hands on the ground or step on any of the lines. If you do your turn ends.
4. Stop and pick up the bean bag while you are still standing on one foot in the second box. Hop over the first box and out of the pattern.
5. Continue to follow this pattern until you have successfully thrown the bean bag into each box, picked it up, and hopped back to the beginning. The *alas*, or "wings," are treated like the double boxes in Pele. Throw the puck first into the left *ala* and then into the right. Never jump into an *ala* with a bean bag in it.
6. When you throw the bean bag into the box below *el mundo* (world), jump into *el mundo* with both feet and then jump again, turning around as you do so. Pick up the bean bag and start hopping back through the pattern and then out.
7. When you have completed the entire pattern, you can place an X or *bimba* (big stomach) in the first box. No other player can land in a square with your *bimba*.
8. No player can place a *bimba* in a square that already has been marked. If the first two squares have an *X* on them, the third player has to make a big jump or get over them. Luckily, the *alas* can be used to jump in on two feet.
9. The player with the greatest number of *bimbas* wins.

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La Thunkuña **Bolivia**

Directions:

1. Throw the bean bag into *lunes* (Monday). Hop over that space into *martes* (Tuesday).
2. Using your hopping foot, kick the bean bag out of *lunes* and back behind the baseline. Then hop out of the baseline. Then hop out of the pattern. (Players can agree to stand on their hopping foot and kick with other.)
3. Toss the bean bag into *martes*. Hop into lunes, then into *miercoles* (Wednesday). Kick the bean bag out of the pattern and then hop out.
4. Repeat for *miércoles*, then for *jueves* (Thursday). When you throw the bean bag into *jueves*, hop into *miércoles*, and then jump into *viernes* (Friday) and *sábado* (Saturday), with one foot in each. Then hop on one foot into *domingo* (Sunday), and kick the bean bag back behind the baseline as before.
5. Do not throw bean bag into *viernes* or *sábado*. Continue the pattern, throwing the bean bag into *domingo*, and then *el cielo* (heaven). Jump into *el mundo* (world) with both feet. Turn with a leap and then kick the bean bag past the baseline with your hopping foot as before.
6. Always hop over the space where the bean bag lands. If your bean bag lands on the wrong day on any toss or kick, you lose your turn. When it's your turn again, start where your last turn ended. The player who gets through the entire pattern first wins the game.

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Pele **Aruba**

Directions:

1. Throw the bean bag into box 1.
2. Hop with one foot into box 2. Then jump into boxes 3 and 4, with one foot in each box.
3. Hop with one foot into box 5, and jump into boxes 6 and 7, with one foot in each box.
4. Jump and turn 180°, landing in boxes 6 and 7 but facing back toward the start.
5. Hope and jump back towards the beginning using one foot in box 5, two feet for boxes 3 and 4, and one foot in box 2.
6. Stop in box two and pick up the bean bag. Jump over box 1 and out of the pattern.
7. Throw the bean bag into box 2 and repeat the pattern, jumping over box 2 and picking up the bean bag on your return. Continue by tossing the bean bag in each box in turn. Never put a foot into a box with a bean bag in it. If the bean bag lands in the wrong box, or outside the pattern, you lose your turn.
8. The first player who completes the entire pattern wins the game.

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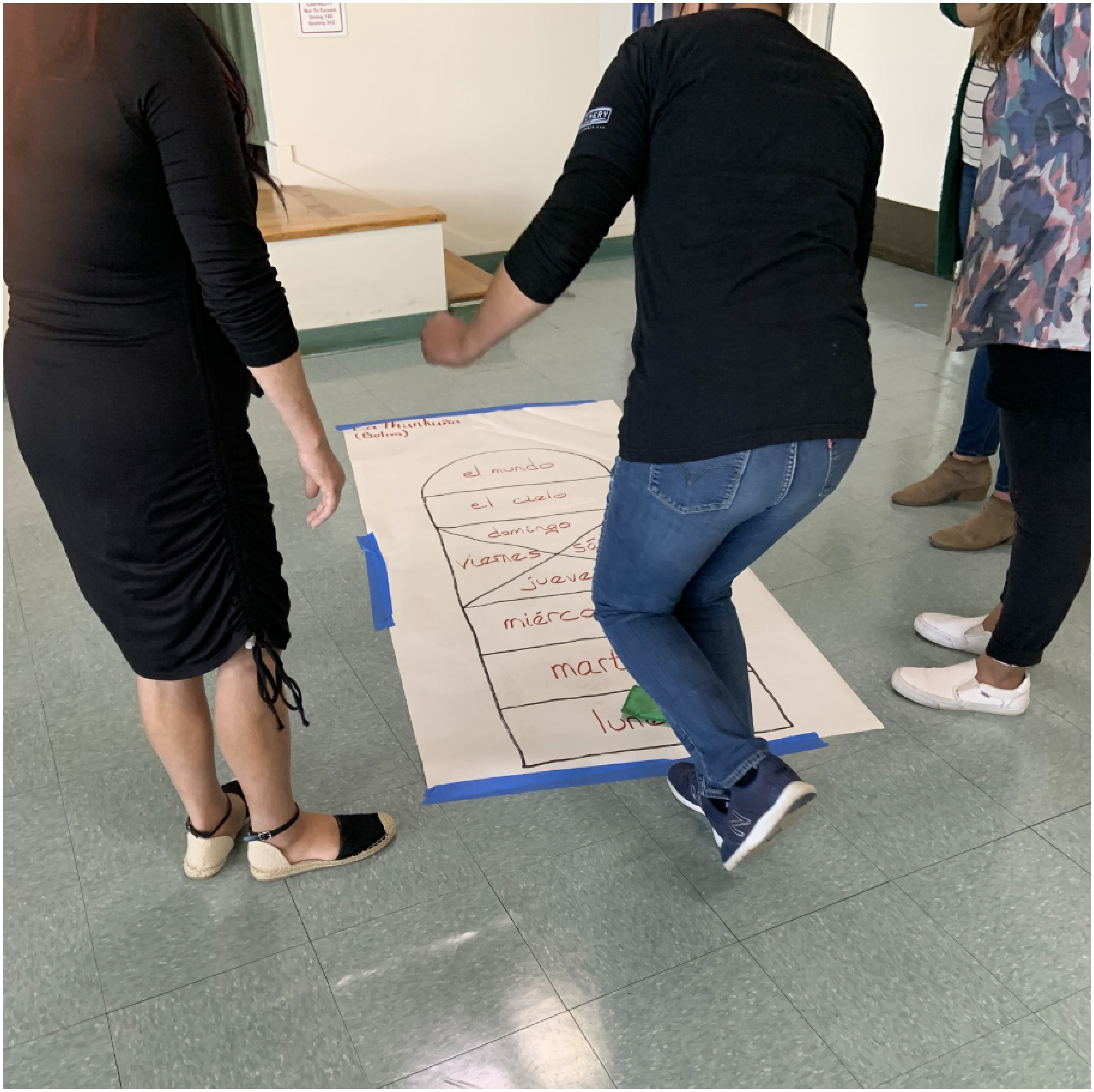
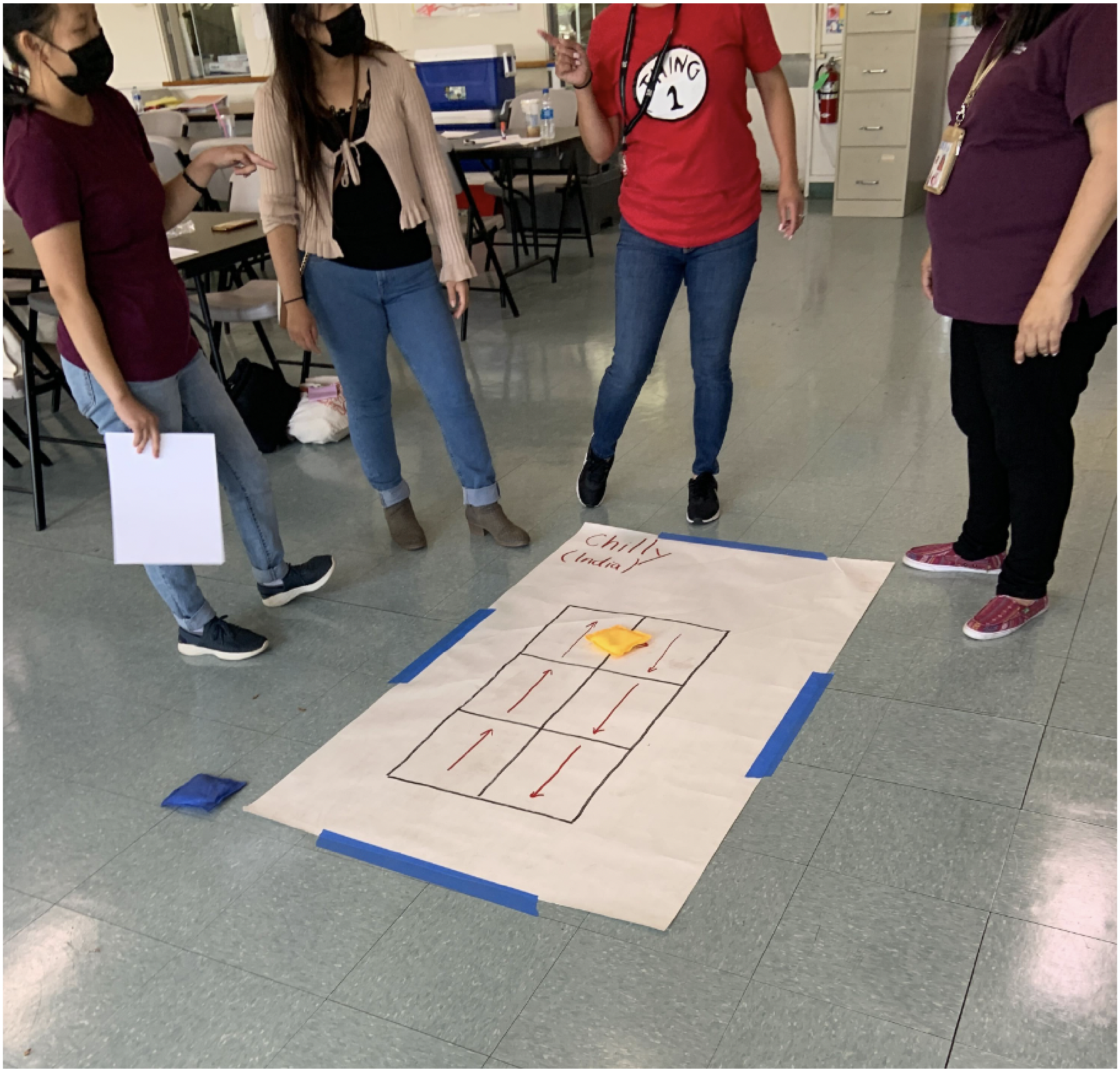
Chilly **India**

Directions:

1. Throw your bean bag into the left-hand box closest to you.
2. Hop with one foot into the box with the bean bag in it.
3. Use your hopping foot to kick the bean bag into the next box. (Players can agree to stand on their hopping foot and kick with other.) Follow the arrows and continue until you are out of the pattern.
4. If the bean bag lands on a line, or goes outside the pattern, or if you put your non-hopping foot down, you lose your turn.
5. When you complete the pattern, pick up your bean bag and return to the baseline. Toss the bean bag into the box just above the first one.
6. Hop over the first box and into the second box. Kick the bean bag around the pattern like before.
7. Continue tossing the bean bag into each box around the pattern. Always hop from the same spot below the first box.
8. The first player to successfully complete the whole pattern wins the game.

aims CENTER


el mundo
el cielo
domingo
viernes


Chilly
(India)


Schedule
Insects
HOPSCOTCH


ART
Schedule
Shapes
ZONE
2
Insects
HOPSCOTCH

EMBODIED FROG SPLASH

AGES 0-5

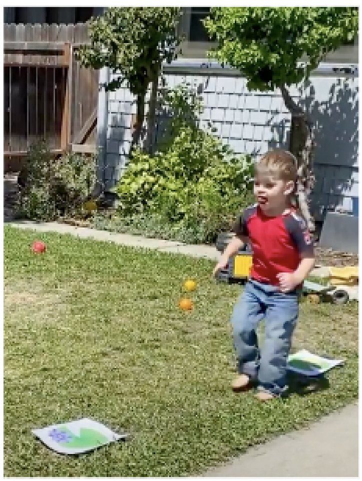
MATERIALS

- Lily pads
- Frog headbands

OBSERVE

Allow the child to explore the material. What are they curious about? How do they want to play with the material? Allow their creativity to drive the play.

CREATE



Create a scene for them to become the frog and bounce from lily pad to lily pad. Tape the lily pad to the wall or place it on the floor. Encourage the child to be creative about how they can move as a frog. Do they want to swim, hop, etc? Then have them count how many moves it takes to get to the pond.

PLAY

Have fun leaping, swimming, and counting! Lily pads can be moved and the game can be changed in many ways. Count together as the child makes their moves.

KEY CONCEPTS

Counting & Cardinality
Child knows number names and the count sequence. Child recognizes the number of objects in a small set. Child compares numbers.

Geometry & Spatial Sense
Child explores the positions of objects in space.

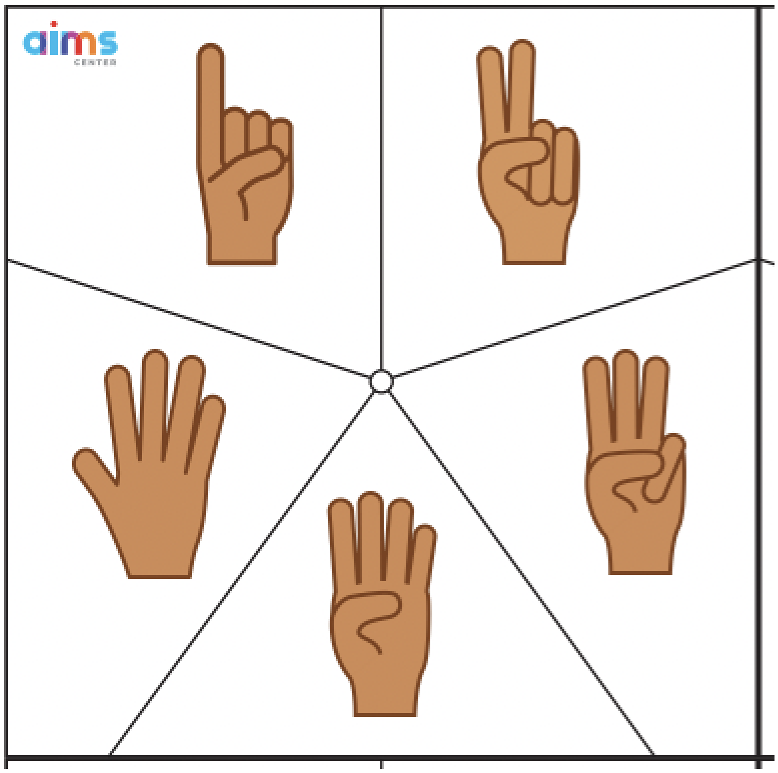
Symbolic Representation & Play
Child uses objects or symbols to represent something else.

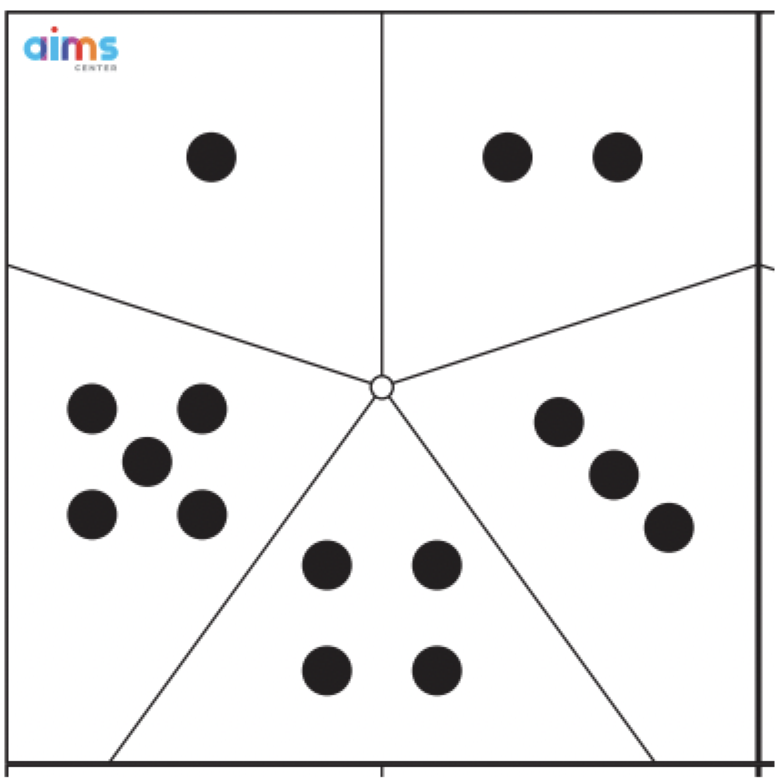
QUESTIONS TO ASK

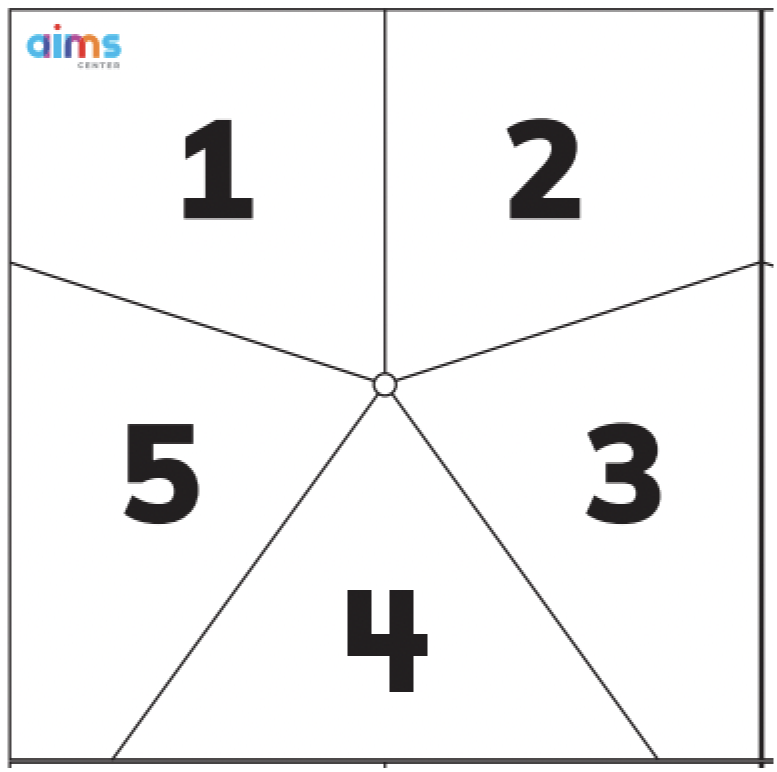
- What do you want to know about frogs?
- How does a frog move?
- Which color lily pad do you want to go next?
- How many lily pads are there?
- What does the frog want to do next?

THINGS TO NOTICE

- Child's creativity with the pretend play.
- Child's large motor movement.
- How high can the child count.



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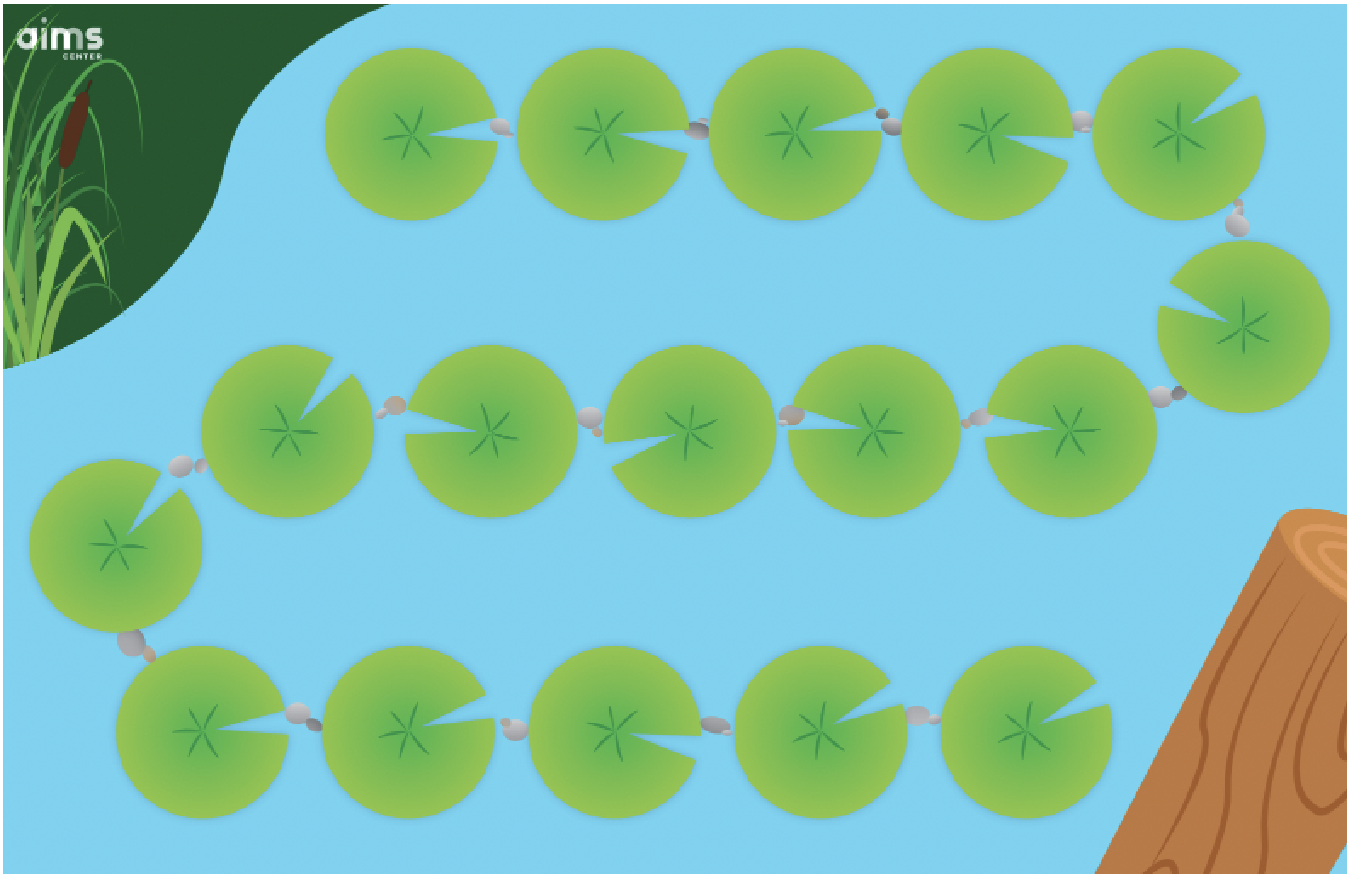

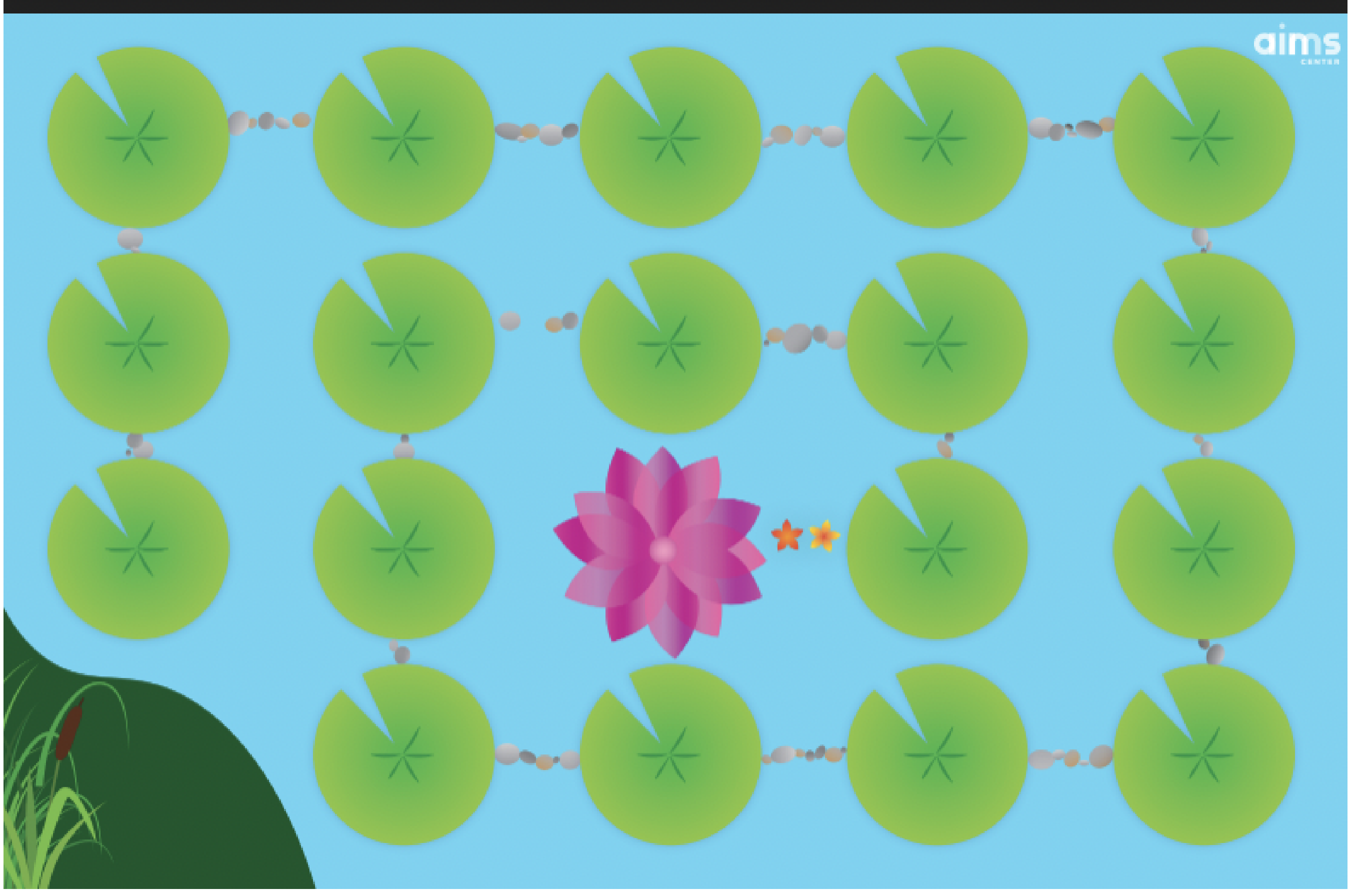

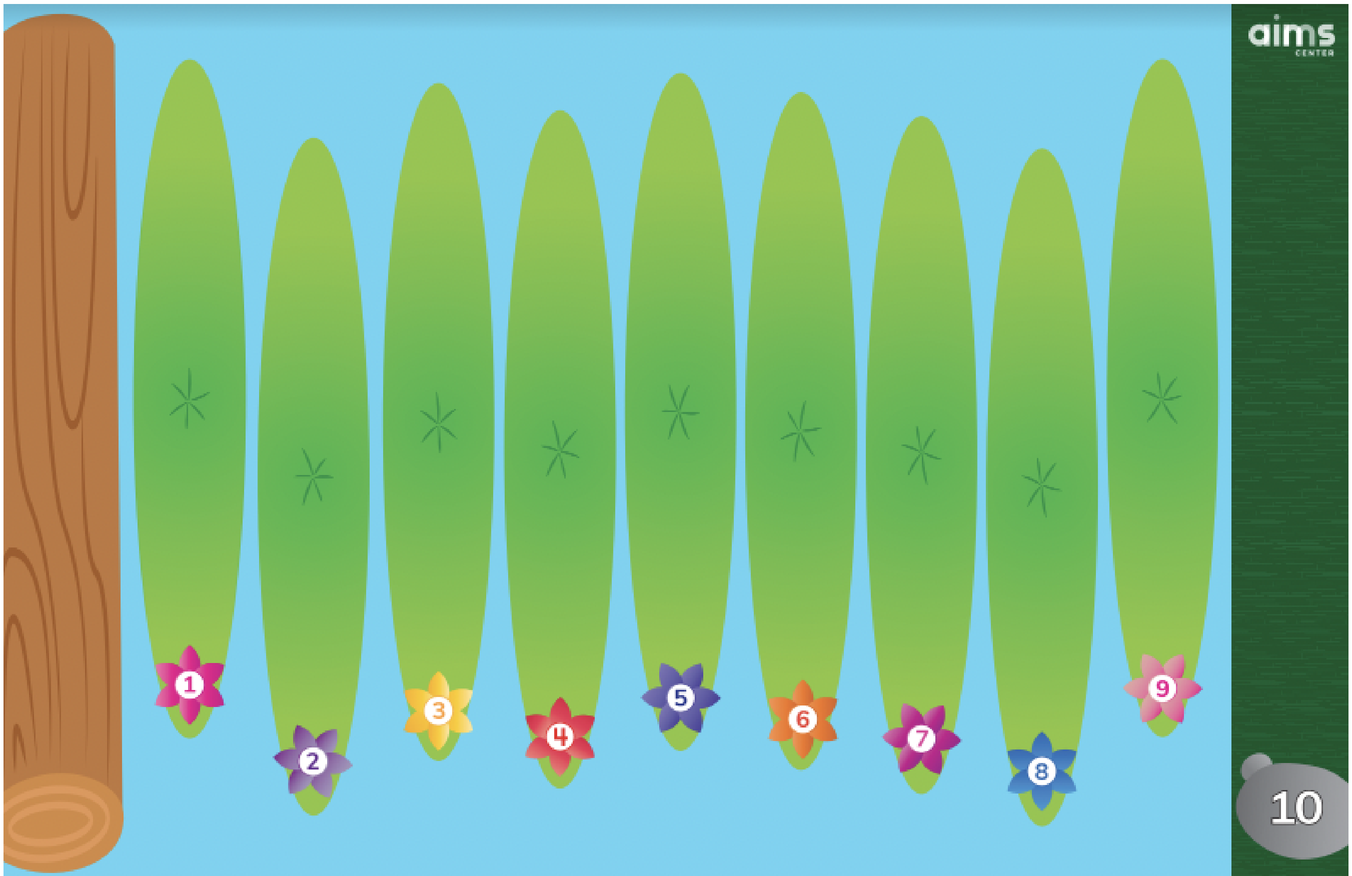
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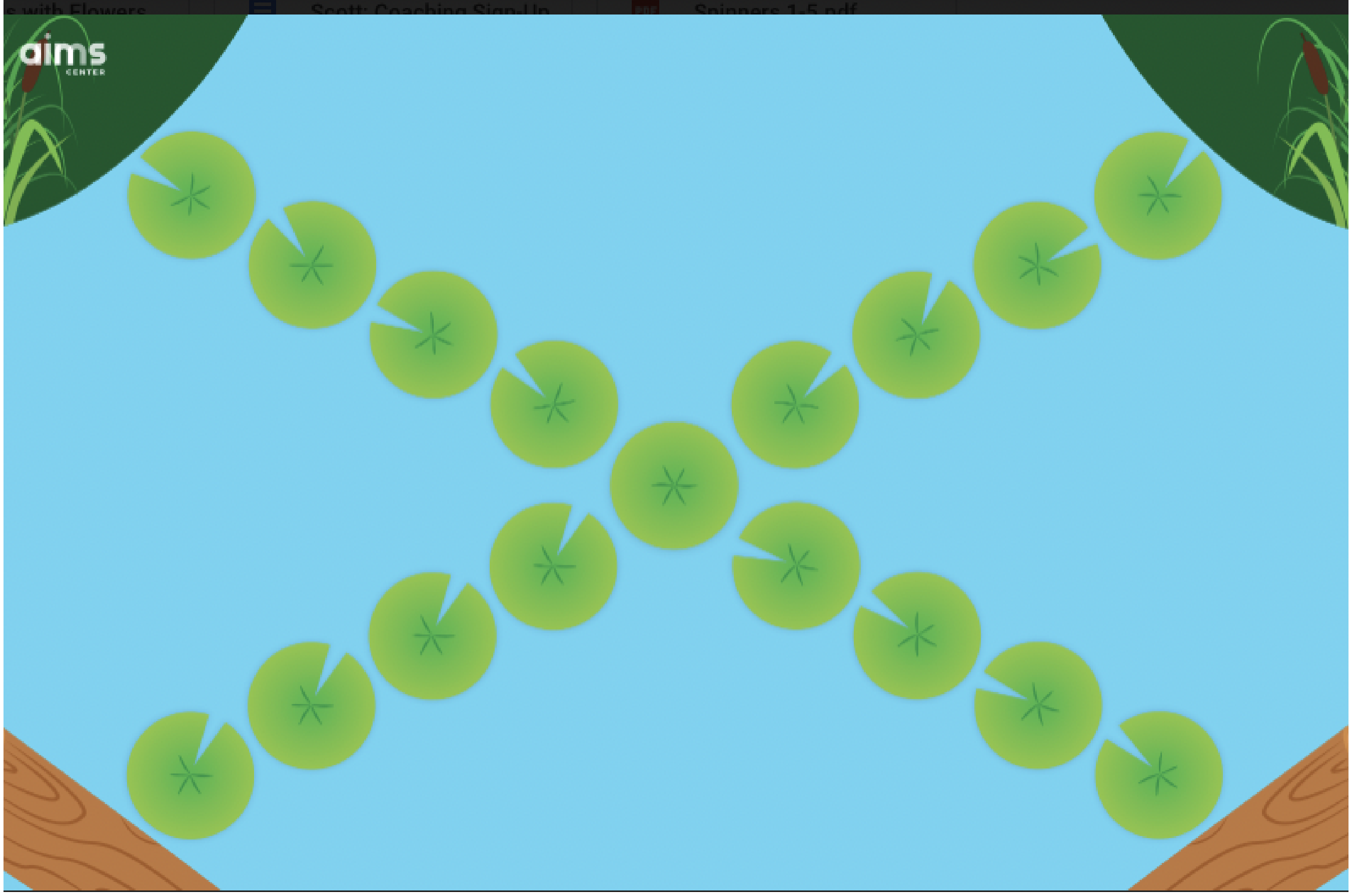
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TINKERING WITH A CATAPULT

AGES 1-5

MATERIALS

- Cup
- Large paint stirrer
- Large rubber band
- Ping pong ball
- Sticky dot or tape
- Strong cylinder : can, water bottle, etc.

KEY CONCEPTS

Geometry & Spatial Sense
Try different ideas and experience what happens.

Plan and Carry Out Investigations
Explore structure and functions as you build and adjust your catapults.

Measurement
Use non-standard (steps, blocks, etc,) or standard (measuring stick, measuring tape, etc.) tools to measure the distance/height.

THINGS TO NOTICE

- Children's curiosity related to the catapult.
- How the child adjusts the catapult.
- How the child measures their achievement of the goal. (distance, height, speed, or accuracy)
- Vocabulary they use to describe what happened.

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OBSERVE

Explain the goal and allow children to explore the material you give them to design and build a catapult.

CREATE

STEP 1. Attach the cup to the paint stirrer using tape or a sticky dot. Press down and hold for 5 seconds.

STEP 2. Loop a large rubber band around one end of the paint stirrer. Then, wrap the rubber band under the cylinder, then back around the paint stirrer on the other side.
*Tip: It is easiest to do this at the ends of the paint stirrer, then slide the cylinder towards to the center once completed.

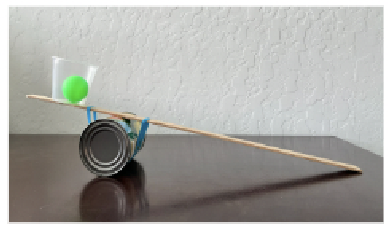
QUESTIONS TO ASK

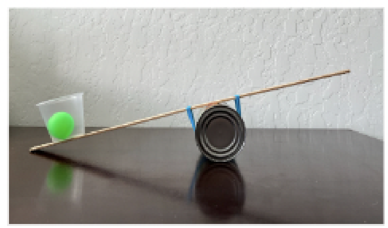
- What is your goal? (distance, height, speed, or accuracy)
- What worked well? What didn't work well? Why?
- How can you measure the distance the object traveled?
- Where do I want to put the cylinder?
- How did the ball fly?
- What else might fly well from the catapult?

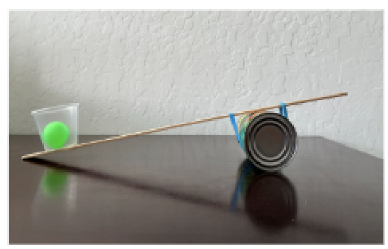
PLAY

After building the catapult have children use the catapult to launch the ball.

→ Adjust how hard you hit the paint stirrer.
→ Adjust the placement of the cup.
→ Adjust the location of the cylinder







Appendix F. Module Descriptions

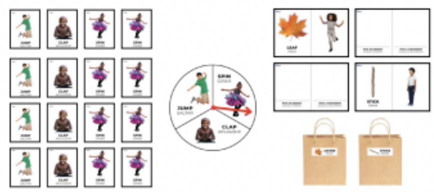
Taken from the Head Start Partnership Annual Report (2021-2022)

https://aimscenter.org/pk12-partnerships

MODULES

In 2021-2022 our partnership focused on playful ways children experience STEAM learning in their everyday environments. Modules engaged teachers and children in exploring:

- → PATTERNS
- → SPATIAL COMMUNICATION
- → MOVEMENT
- → GAMES
- → SIMPLE MACHINES



PATTERNS

- → Where do you see patterns?
- → Can you make a pattern?
- → What kinds of patterns can you make?
- → Can you finish a pattern?
- → Can you tell what the pattern is?
- → Can you extend a pattern?

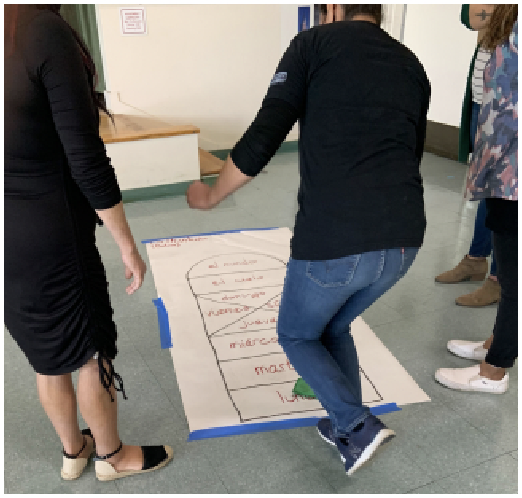
DRDP

- → **Cog 6**: Patterning
- → **Cog 9**: Inquiry through Observation and Investigation
- → **PD-HLTH 1**: Perceptual-Motor Skills and Movement Concepts
- → **VPA 1**: Visual Art
- → **VPA 2**: Music
- → **VPA 4**: Dance

Sample Activity

Participants explored sound, visual and movement patterns by rotating through three centers.

5



GAMES

- Types of games - individual, goal oriented, competition, teamwork/ cooperative
- Monitoring count and movement
- Skills taught by board games
- Attention to rules of a game and making up new rules

DRDP

- **Cog 1**: Spatial Relationships
- **Cog 3**: Number Sense of Quantity
- **Cog 4**: Number Sense of Math Operations
- **Cog 6**: Patterning
- **Cog 9**: Inquiry through Observation and Investigation
- **PD-HLTH 1**: Perceptual-Motor Skills and Movement Concepts

Sample Activity

Teachers explored different versions of the game hopscotch from around the world.

SIMPLE MACHINES

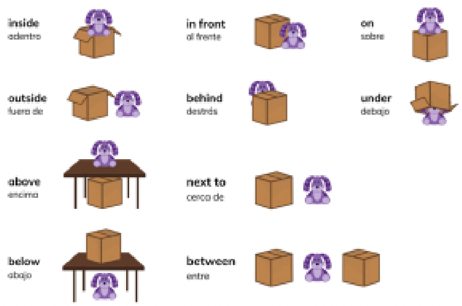
- How do robots and other simple machines work?

DRDP

- **Cog 1**: Spatial Relationships
- **Cog 3**: Number Sense of Quantity
- **Cog 4**: Number Sense of Math Operations
- **Cog 6**: Patterning
- **Cog 9**: Inquiry through Observation and Investigation
- **PD-HLTH 1**: Perceptual-Motor Skills and Movement Concepts

Sample Activity

Each classroom received a Hexbug kit and three Matata Lab Coding Kits which are now available for classrooms to check out and provide coding experiences for students.



SPATIAL COMMUNICATION

- When and how do people use spatial communication?
- What goals do we have when we use spatial communication?
- What can you use to aid in spatial communication?
- Can you visualize objects and move them in your mind?
- Can you give the same directions in multiple modes?
- How can your body help you communicate spatially?

DRDP

- **Cog 1**: Spatial Relationships
- **Cog 9**: Inquiry through Observation and Investigation
- **PD-HLTH 2**: Gross Locomotor Movement Skills
- **PD-HLTH 3**: Gross Motor Manipulative Skills
- **VPA 4**: Dance

Sample Activity

Teachers worked in small groups to give directions to an AIMS coordinator on the Franklin campus to get from one location to another.

MOVEMENT

- How do people move their bodies?
- What goals do we have when we move our bodies?
- What else moves?

DRDP

- **Cog 1**: Spatial Relationships
- **Cog 9**: Inquiry through Observation and Investigation
- **PD-HLTH 1**: Perceptual-Motor Skills and Movement Concepts
- **PD-HLTH 2**: Gross Locomotor Movement Skills
- **PD-HLTH 3**: Gross Motor Manipulative Skills
- **VPA 4**: Dance

Sample Activity

Participants explored movement through several activities including working in a group to make a geometric shape with a stretchy band, directing a partner where to go using tiles on the floor as a grid, interactive yoga, and brainstorming favorite movement songs.

Just Fun Pictures


RAFFLE
DROP BOX


aims
CENTER

Chapter 5. Discussion

This chapter summarizes the three studies presented in this dissertation and shares important takeaways from each study. I also describe the future directions of this work.

Summary of Findings

Through this dissertation, I aimed to increase our understanding of both how we can support students in STEM and math learning, as well as provide support and access to teachers in teaching STEM and math content. I also employed different study designs and analysis methods across the three studies included, showing that it is important to explore different ways in which we can uncover mechanisms behind STEM teaching and learning (Table 1). The first two studies display how supports can be used to aid in student learning on online platforms. Study one explored how to present worked examples to students best as they complete algebra problems. Study two explored how spatial skills and problem supports, in the form of presentation formats, impact problem-solving performance. These studies have important implications for the future design of student support in online problem sets. Both studies show that the format of support may not be as important as practicing the skills themselves and leave interesting questions on the customization or choice in problem supports that students or teachers may be able to employ in the future. Future work on these two studies will explore student and teacher choice in the presentation format of problem support, and how this choice impacts performance and learning.

Table 1. Summary of studies

	Population	Content	Study Design	Analysis	Effect
Study 1	Algebra 1 Students	Algebra	Randomized Controlled Trial	Bayesian & Frequentist ANOVA	All WEs effective

Study 2	Middle School Students	Geometry	Randomized Controlled Trial	Linear Regression	Spatial skills predict performance above and beyond support
Study 3	Early Childhood Educators	STEM	Survey & Interview	Thematic Analysis	Teachers gain confidence & expand and implement activities for classroom use

The third study in this dissertation shifted the focus from supporting students to training teachers, with the same overall goal of increasing access to supportive and helpful STEM activities for students. This study also focused on a much younger population, since early positive STEM experiences can be impactful (Clements& Sarama, 2016). Teachers play a vital role in student learning. Beyond affecting small, short-term, changes in students' learning, it is important to study the long-term and lasting effects which professional development can have on teachers, and in turn, the many students they will continue to serve over the years. The outcomes of this work add to the literature on how we can increase teachers' attitudes and confidence toward STEM through professional development training. Additionally, we explored the mechanisms by which teachers implement and expand STEM activities provided to them through professional development. It is important to explore what teachers do after the specific professional development is completed, to fully understand how professional development can be effective and provide recommendations for the design of professional development programs. This project is continuing for the 2022-2023 school year, and we have plans in place to expand to other Head Start sites for the 2023-2024 school year and beyond. The outcomes from this work have already been applied to the design of other professional development programs through an iterative process. We have been continuing to collect data from this year's program and will delve into that data to uncover long-term effects of the program for teachers and students and provide recommendations for sustaining partnerships and designing successful professional development programs. Further, we will examine the barriers in place to accessing and participating in professional development programs and STEM teaching in preschool.

Limitations and Future Directions

While each of these studies employed different methods and designs and targeted different populations, they give us only a snapshot of the entire picture of STEM education. To uncover the whole picture of STEM education it is important to combine the strengths and weaknesses of each of the studies. For example, while studies one and two explored student learning and support through quantitative analyses, study three solely focused on teachers and could benefit from exploring student learning as well as quantitative measures of teacher and student impacts. Conversely, while study three focused on teachers and qualitative data, studies one and two could benefit from teacher training and feedback in the topics of geometry and algebra support, as well as qualitative data on student and teacher perceptions of the support materials. Additionally, all conclusions in this dissertation are also only applicable to the direct populations they observed and could benefit from further exploration in other age groups and content.

Mixed methods research

Study one explored the effects of different worked examples on student learning within an online homework platform. However, this study used a pre and post-test to measure the impact of the worked examples, limiting our conclusions. Expanding on this work, my colleagues and I further explored the impact of different worked example presentations. We explored both algebra 1 and college student written feedback and perceptions on the different worked example presentations (Closser, et al., November, 2022a; Closser, et al., November 2022b). By combining both qualitative and quantitative data, we can uncover a broader picture of the impacts and helpfulness of different worked example presentations and determine which formats students prefer, leading to future work uncovering the effects of student choice in worked example format. We are also currently collecting data for another study on worked example formats in which we explore how student action and explanation in worked example practice affects learning.

Study three presents results from a qualitative analysis of teacher experiences during a professional development program. This study could be strengthened with the inclusion of quantitative measures. As we continue to conduct professional development programs with head start teachers we intend to include measures of teachers' knowledge of STEM concepts, computational thinking skills, and their confidence in teaching and self-efficacy. Additionally, we plan to collect student data on the impact of the professional development program. This quantitative data, combined with the existing qualitative data will strengthen our claims on the impacts of the program.

Teacher Training in Algebra and Geometry Supports

Studies one and two provide recommendations and outcomes of how we can support student learning within online environments when learning algebra and geometry. However, one main aspect of student learning in geometry and algebra is the teachers. To expand this work it is important to provide recommendations and training to algebra 1 and geometry teachers on how they can support students through small manipulations, problem design, and hints, which mirror what students see in online environments.

Student Outcomes of Professional Development Programs

Professional development programs, conducted with teachers, are expected to have impacts on student learning (Caprano et al., 2016; Emery et al., 2019). However, many professional development programs measure only the impacts on teachers, with a push to measure student outcomes (Earley & Porritt, 2014). Future plans for continuing the work of study 3, include collecting student data. To truly examine the impact of the professional development program it is important to collect data from all possible people who may be impacted by the program. We also plan to collect data from parents, who receive STEM activities for their homes. We plan to collect both qualitative and quantitative data from students in the form of classroom observations, student surveys, parent surveys, and student end-of-the-year reports. Further, an ultimate goal is to collect longitudinal measures of student outcomes, such as standardized testing scores.

Expanding Study Populations

Study one explored worked examples for Algebra 1 students. To further explore the effects of worked examples and to be able to generalize across populations, it is important to explore the effects of worked examples with other age groups and on other math content. Additionally, while study two explored the impact of mental rotation skills on geometric transformations, it is important to further explore the effect of spatial skills on other geometry and math concepts and with other age groups. My goal is to run replication studies with different student populations.

Study three explores the effects of a professional development program in Head Start preschools in California. To generalize the effects of the professional development program, it is important to expand the program to different preschools and different areas. For example, beyond continuing the program within California Head Start preschools, I plan to conduct aspects of this program in preschools in Massachusetts.

Conclusion

The three studies presented in this dissertation provide a broad overview of some of the ways we can increase access to, and positive experiences around, STEM learning through training teachers as well as supporting students. While this work has the potential to contribute to our theoretical understanding of problem support and teacher training, I believe the true value of this work lies in the applications to classrooms and work with teachers. The potential impacts on preschool students and teachers are innumerable. While study three directly impacted 26 teachers and their 131 students of the 2021-2022 school year, the impacts on each teacher have the potential to impact all of their future students. Additionally, this program laid the foundation for a strong and continuing partnership, which is growing to include other Head Start sites. As we continue to build upon this partnership, work with the same teachers again, and work with new teachers, this program has the potential to impact many individual students and teachers.

Lessons Learned & Future Directions

My journey through to this degree has been winding and taken some turns and twists along the way. However, coming out of this path, I believe my future path is clearer and straighter (I say this now, knowing there will be bumps and turns in the road). However, for now the road is straight and the horizon is in view! Through this journey I was able to explore different contexts, topics, types of research, and explore other facets of higher education beyond the research world. I have conducted randomized controlled trials to uncover small changes that may make assignments easier for students. I have designed and conducted professional development programs across topics. I have explored student perceptions of up and coming terminology. I have participated in numerous outreach and community programs. And finally, I have had opportunities to teach and mentor. I have found that my true passions are in teaching, mentoring and working with students. I have also found passions in designing and conducting professional development programs for teachers. I have learned that I value work in which I can directly see the impacts and work which provides strong and measurable real-world impacts. I enjoy research that allows me to work directly with the populations I am studying, rather than sitting behind a computer screen. I also truly value working with my community and participating in outreach. In my future work I hope to continue to teach and mentor. I also hope to continue to work with communities, on research and outreach.

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