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Moving Forward, Leaning in: Acceleration over Remediation

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RCML History

The Research Council on Mathematics Learning, formerly The Research Council for Diagnostic and Prescriptive Mathematics, grew from a seed planted at a 1974 national conference held at Kent State University. A need for an informational sharing structure in diagnostic, prescriptive, and remedial mathematics was identified by James W. Heddens. A group of invited professional educators convened to explore, discuss, and exchange ideas especially in regard to pupils having difficulty in learning mathematics. It was noted that there was considerable fragmentation and repetition of effort in research on learning deficiencies at all levels of student mathematical development. The discussions centered on how individuals could pool their talents, resources, and research efforts to help develop a body of knowledge. The intent was for teams of researchers to work together in collaborative research focused on solving student difficulties encountered in learning mathematics.

Specific areas identified were:

1. Synthesize innovative approaches.
2. Create insightful diagnostic instruments.
3. Create diagnostic techniques.
4. Develop new and interesting materials.
5. Examine research reporting strategies.

As a professional organization, the **Research Council on Mathematics Learning (RCML)** may be thought of as a vehicle to be used by its membership to accomplish specific goals. There is opportunity for everyone to actively participate in **RCML**. Indeed, such participation is mandatory if **RCML** is to continue to provide a forum for exploration, examination, and professional growth for mathematics educators at all levels.

The Founding Members of the Council are those individuals that presented papers at one of the first three National Remedial Mathematics Conferences held at Kent State University in 1974, 1975, and 1976.

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Moving Forward, Leaning in: Acceleration over Remediation For Mathematics Learners

FOSTERING SYSTEMIC COHERENCE THROUGH A SHARED VISION OF HIGH-QUALITY MATHEMATICS INSTRUCTION

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Recent research on instructional vision offers new insights into the challenges of systemic coherence when implementing educational innovations at scale. In this paper, we retrospectively examine the work of our statewide partnership of mathematics education leaders for implementing new state mathematics standards. We identify three categories of designs that improved coherence during implementation and highlight the role of instructional vision in each.

Innovations that aim to create meaningful and sustained improvements in classroom instruction and student learning often fail when scaled. A successful implementation requires coordination and leadership across multiple levels of an educational system (NRC, 2012), and policy researchers have long posited that a misalignment among curriculum materials, assessment systems, and evaluation systems is a significant impediment to reform efforts. Yet despite the significant resources often allocated to alignment during implementation, systemic coherence is rarely achieved.

Recent research on instructional vision offers new insights into the challenges of systemic coherence when implementing educational innovations. Instructional vision is a discourse educators use to characterize ideal classroom practice (Munter, 2014), and researchers have shown that a teacher's vision relates to instructional changes over time (Munter & Correnti, 2017), influences how they filter competing messages about practice (Tichnor & Schwartz, 2017), and is shaped by interactions within professional networks (Munter & Wilhelm, 2021).

In this paper, we argue that instructional vision provides new explanations for longstanding challenges of implementation and new ways of promoting systemic coherence. We examine the work of our statewide partnership of mathematics education leaders for implementing new state mathematics standards, identify three categories of designs that improved coherence during implementation, and highlight the role of instructional vision in each. By doing so, we aim to support other researchers working in partnership with education leaders to support implementation efforts within and across school districts.

Background

More than thirty years ago, the National Council of Teachers of Mathematics (NCTM) released *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) and with them a vision for school mathematics where students engage in rigorous mathematics content and the practices of mathematicians. This effort marked the beginning of an era of standards-based reform in the United States where policy makers have sought to shape classroom instruction at scale through the allocation of resources and accountability systems. Thirty years later, states and national organizations are still setting mathematics standards that embody this vision. And though some modest advances in student outcomes have been made, standards-based reform has yet to yield significant improvements in mathematics teaching at scale and has failed at addressing the opportunity gap.

Implementation scientists and educational policy researchers have identified obstacles, developed explanations of these shortcomings, and provided insights into the complexity of large-scale systemic reform. For example, educators implementing a new policy tend to focus on its surface features or attend to its similarities with existing policies while ignoring substantive changes and meanings behind them (Spillane et al., 2002). Scholars have repeatedly underscored how efforts aimed at large-scale instructional change place significant demands on both individuals and educational organizations and require opportunities and a significant amount of time for both individuals and organizations to learn (Fullan & Pomfret, 1977). Without such opportunities, multiple interpretations of a new policy and the changes it requires lead to conflicting goals, competing priorities, and incoherence.

There is growing recognition that systemic reform requires coherence; that is, all components of an educational system must work together in support of the vision of teaching and learning underlying the policy (NRC, 2012). Following recommendations from policy researchers, educational leaders have primarily sought to achieve systemic coherence during reform through aligning curricula, assessments, professional development, and evaluation systems with academic standards (Smith & O'Day, 1990). These efforts to create coherence have become central to national organizations' (e.g., WestEd, CCSSO,) recommendations to states and large districts when planning for large-scale implementation. For example, the Center for Standards and Assessment Initiatives' standards implementation framework centralizes alignment in a comprehensive, research-based plan for adopting and implementing academic standards (CSAI, 2019). During the earliest phases of implementation, for example, the framework recommends developing a crosswalk document that links previously and newly adopted standards and serves to guide alignment. Though important, an exclusive focus on alignment fails to consider the tendency for educators to recognize only superficial changes and similarities with existing standards (Spillane et al, 2002). By mapping familiar standards to new, more ambitious ones, such documents signal little change is required.

Some scholars have started to question whether standardized approaches to implementation like alignment will lead to meaningful changes in instruction and systemic coherence because of the significant learning required to change instruction (e.g., Penuel et al., 2009). They argue that coherence is not an objective characteristic of an educational system with all components working synchronously but rather a subjective meaning made by an individual of how that system works. Instead of being a state of perfect alignment, coherence is an ongoing process by which individuals create meaning of reform in their local contexts (Honig & Hatch, 2004). From this perspective, the success of reform largely depends on the ways that educators actively interpret policies and what they prescribe, perceive an alignment of resources and messages with intended goals, and engage in collective sensemaking in their local contexts to "craft coherence."

In the context of reform, academic standards communicate a particular vision of teaching and learning that differs from those held by most educators. Yet the prevailing approaches to standards implementation either a) assumes this vision is shared among educators throughout the system, b) that only key leaders have the vision and can share the vision at scale in the midst of implementation, or c) disregard the vision altogether. In fact, recent research indicates that the visions of high quality mathematics instruction (VHQMI) held throughout educational systems vary (Munter, 2014) and do not automatically change in the context of reform, even with significant professional learning opportunities (Munter & Correntti, 2017).

Theoretical Perspectives

An instructional vision focuses on concrete, "ideal images of practice" (Hammerness, 2006, p.1) with tangible details of content and how students will engage in it. Significant advances have been made in characterizing instruction that supports all students in learning mathematics. Characterized by some as high-quality mathematics instruction, instruction that meets these goals aims for teachers to be intentional in supporting students, for example, by problematizing ideas, supporting students in developing mathematical authority, and scaffolding classroom discussions in ways that formalize learning goals for students. Instruction enacted toward these goals has positive implications for learning.

Established and emerging research suggests that sharing a VHQMI can support successful implementation of new programs or policies (Gamoran, 2003), relates to improved instructional quality (Munter & Correnti, 2017), can lead to improvements in students' academic outcomes (Chance & Segura, 2009), and is an indicator of future practice (Cobb et al., 2018). Munter (2014) developed and tested a set of rubrics to track educators' descriptions of instruction and their alignment toward research-based descriptions of VHQMI. These rubrics articulate VHQMI along several dimensions and have been used in studies focused on mathematics teachers (Munter & Correnti, 2017), leaders (Jackson et al., 2015), and principals (Katterfeld, 2015).

While promising, research also points to the ways in which educators' visions are shaped by participating in different social contexts (Munter & Wilhelm, 2021) and informed by different or conflicting messages from both inside and outside schools (Ticknor & Schwartz, 2017). Teacher collaboration, PD, and productive collaborations across educator roles are rarely effective unless they are tied to a shared vision of instruction (Peterson et al., 1996). The importance of common vision is reflected in Cobb and Jackson's (2011) theory of action for large scale instructional improvement in mathematics, which includes VHQMI underlying a coherent instructional system as one of five key elements of their theory.

We argue that the growing body of research related to instructional vision provides new insights into the challenges of reform and the lack of significant instructional changes occurring in the classroom. Disparate visions help explain the different interpretations educators have and act upon during implementation. The relationship between VHQMI and instructional change suggests that the outcomes of a reform initiative may be understood as the extent to which the visions held by the system are compatible with the vision promoted by standards.

Method

To better understand the role instructional vision plays in promoting coherence, we retrospectively examined the work of our partnership with mathematics leaders in our state to support the implementation of new state mathematics standards. By studying the supports developed by the partnership and the degree to which they reflected VHQMI, we aimed to identify and describe categories of designs that facilitate the development of a shared instructional vision and promote coherence when implementing innovations at scale.

Context

The North Carolina Collaborative for Mathematics Learning is a partnership of researchers from 13 UNC campuses, mathematics leaders in the state education agency, and over 300 collaborating district leaders, instructional coaches, and mathematics teachers. The partnership formed in 2016 when the state began adopting new K-12 mathematics standards and has taken a design-based implementation research approach (Fishman et al., 2013) since then to collaboratively develop implementation resources, create professional learning materials, and grow a statewide network to support teaching and learning through networking and advocacy.

From 2016 – 2019, the partnership iteratively developed a number of resources that have been accessed and used widely by mathematics educators statewide, including 25 online professional learning modules for high school mathematics accessed by approximately 3,600 mathematics teachers and leaders to date, 36 research-practice briefs developed to assist vertical alignment and share research on student learning that have been downloaded over 13,350 times, and 15 grade- or course-specific instructional frameworks that cluster and sequence the new standards used or adapted by all 115 school districts as well as many of the public charter schools. The partnership has also developed virtual platforms for sharing resources and developing community, convened meetings for examining data, facilitated professional learning experiences, and created alternative communication structures for sharing information about statewide policy changes and advocacy.

Data and Analysis

To examine how these designs promoted a shared VHQMI, we produced and examined conjecture maps (Sandoval, 2014) for each iteration of our major designs between 2016 – 2019. Sandoval argued that any design is an embodiment of the designer's conjecture about how its aspects will lead to some desired outcome and describes conjecture mapping as a tool for empirically investigating and elaborating theories of learning and design. Conjecture maps begin with a high-level conjecture about how a particular design will lead to a desired outcome. Using a set of principles derived from theory, evidence, and commitments, the conjecture is embodied in a set of design features. Design conjectures describe how these features are intended to lead to some mediating processes, which in turn are conjectured to result in some learning outcome. After an iteration, a new conjecture map represents a revised embodiment of the high-level conjecture and includes any changes to the features, design conjectures, or learning conjectures.

In addition to the conjecture maps, we created "problem analysis" (Edelson, 2002) memos describing the goals for each design, the contextual resources and constraints each, and the procedures and expertise used by the partnership to develop them. Summarized from partnership documents, meeting notes, and our collective reflections, the memos capture our understanding of the state educational system both at the time of design and retrospectively.

Our analysis of the conjecture maps and problem analysis memos proceeded in two phases. First, the research team independently examined the data and created analytic memos identifying categories and characteristics of the partnership's designs, common procedures and kinds of expertise used to develop them, and abstractions of common influences and constraints imposed by the system. Collectively, the team discussed their independent analyses until consensus was met and used the results to develop categories of the partnership's design efforts. Next, we examined each of these categories to describe how VHQMI was embodied in the designs. This layer of analysis highlighted places where instructional vision was prominent, tacit, and absent and provided an opportunity to refine our designs for future iterations of research.

Designs Promoting a Shared VHQMI for Coherent Standards Implementation

Through our analysis, we identified three categories of designs – implementation resources, implementation practices, and implementation structures – that we conjecture are critical in developing a shared VHQMI when implementing state mathematics standards. In what follows, we describe the goals, characteristics, the role of instructional vision for each category and provide examples from our partnership.

Implementation Resources

Implementation resources refer to the material designs useful for promoting collective sensemaking. The goal for designs in this category is to provide immediate guidance and support for teachers and leaders that highlights what is novel about the innovation (Spillane et al., 2002). They are tools that are either unavailable or those that are not yet refined to consider the innovation. Implementation resources are grounded in research on teacher and student learning, instruction, and implementation. They provide access to safe, professional learning opportunities and represent the expertise of a diverse set of educators within the system. These designs embody a sophisticated VHQMI, contain representations of high quality instruction, and feature artifacts of learning that showcase students' social, cultural, and mathematical resources.

The 15 grade- or course-specific instructional frameworks are an example of an implementation resource developed by the partnership. In 2017, the K-8 mathematics standards were revised and mathematics education leaders called for a set of resources that would support implementation. In the past, school districts developed their own pacing guides; however, stakeholders lamented that the large diversity in pacing guides was a barrier to coherence and enactment of teachers' VHQMI. Therefore for each grade level and course, the partnership collaboratively designed state-wide pacing guides, re-named instructional frameworks (IFs) to denote that they would go beyond prescriptive time frames for teaching certain standards by including resources that supported their implementation. Co-designers began their work by reviewing relevant research, revisiting their commitment to promote a shared VHQMI, and deciding on a format for the resource so that teachers could use them with relative ease. To ensure that the IFs would prompt safe, professional learning experiences, a set of research-based design principles were developed so that the frameworks emphasize curriculum guidance and not prescriptive pacing, focus on central ideas with links to high quality curriculum materials, allow for flexibility and unpredictability based on differences in contexts, and address development of student reasoning from an asset orientation and how to build upon it.

Implementation Practices

Implementation practices refer to routines for accessing the social resources and expertise distributed throughout a system. The goal of designs in this category is to introduce and sustain forms of interaction that disrupt normative behaviors and build productive, mutually respectful professional relationships among educators across levels of a system. These designs promote generosity and empathy in cross-role and cross-organizational sensemaking, a sense of community beyond one's school or district, and challenge the historic narratives and practices about individualism endemic in public education discourses. Implementation practices are designed to surface diverse instructional visions for discussion and revision.

Boundary crossing (Wenger, 1998) is an example of an implementation practice developed by the partnership. Historically, district and school mathematics leaders across the state typically worked within their own districts to prepare for new standards implementation, with each district creating its own resources and tools to the extent possible based on local capacity. While larger districts were typically more confident and prepared to implement new standards, smaller and under-resourced districts were left to prepare and navigate implementation in isolation, often with very little support for their teachers. In developing, refining, and distributing implementation resources, the partnership convened groups of educators from different roles and districts, developed regular routines for participation with educators from different roles and different contexts, and committed to freely and openly sharing across organizational boundaries. As these forms of participation became normalized, they were occasions for disparate instructional visions to be uncovered, discussed, interrogated, refined, and shared over time.

Implementation Structures

Implementation structures refer to mechanisms for locating and sharing information within a system and can either augment or replace existing structures that influence instructional practice. The goal of these designs is to share information across the system using communication networks, relationship-building, and just-in-time advocacy to address the ways new initiatives or parts of the system are and are creating conditions for successful implementation. Implementation structures identify current and future systemic issues that will affect implementation efforts and facilitate formal and informal communication with influencers and experts in the system who can address such issues. These designs complement existing structures and connect organizations in new and productive ways and provide a means for egalitarian access to information, especially those closest to the learning. Because instructional visions are produced and reproduced in professional discourses, implementation structures facilitate the development of a shared and more sophisticated VHQMI.

Our partnership's communication network – including social media platforms, email lists of professional and personal addresses, and group text channels – is an example of an implementation structure. Because formal communications within the state educational system are hierarchical and largely ineffective, our partnership developed a system for sharing timely information with a broad audience. After implementing new standards, the state agency's assessment division began their process of seeking input from teachers about which standards should be tested on new formative assessments administered quarterly. Many of our district partners reported that the clustering and ordering of these assessments would dictate local pacing and other instructional guidance resources, regardless of their existing curriculum or other implementation resources developed by the partnership. Using our communication network, the partnership was able to alert teachers and district leaders and provide information on how to volunteer to attend a meeting to provide feedback on draft test specifications. Teachers and leaders from across the state responded, and the quarterly formative assessments were ultimately aligned with the partnership's implementation resources. As an implementation structure, the communication network was essential in creating opportunities for developing a shared VHQMI.

Discussion

The goals and characteristics of implementation resources, practices, and structures are the beginnings of what Edelson (2002) calls a design framework that can be used by other mathematics education researchers and leaders who wish to foster systemic coherence in support of implementation efforts. Building from findings from recent research and the ongoing work of our partnership, the framework highlights the importance of attending to instructional vision when implementing educational innovations at scale.

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MATHEMATICS LEARNING LOSS DUE TO INTERRUPTIONS IN FORMAL EDUCATION

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Results from interim benchmark assessment during the COVID-19 pandemic showed that students' performance in mathematics declined at the beginning of the pandemic and worsened by the end of the 2020-21 school year. Further analysis on the data revealed that students in elementary grades registered more loss than students in middle grades. This study explores mathematics learning loss for 48 schools in grades 3-5, focusing more on the domains or goals of mathematics that are tested in these grade levels, to find out if all domains were equally affected.

Introduction

When schools closed in winter of 2020 due to the pandemic, many schools did not immediately go into online mode. Even the few that did, they did so without the instructional expertise. The fact that some students continued with online learning and others did not have any form of instruction during the early days of the pandemic created inequalities in access to learning. By the end of the 2019-2020 school year, many states had put mechanisms in place to ensure that online learning was a means to bridge these educational inequalities. By the beginning of the 2020-2021 school year, measures to mitigate some of the remote learning issues students faced earlier in the pandemic were done by providing computers and in other cases, by having Wi-Fi hubs stationed in areas where students would come and connect to internet. While some schools had online learning and others had in-person learning, a majority of schools provided a hybrid model offering instruction delivery that included both in-school and online learning.

Preliminary fall 2020 reports from Northwest Evaluation Association (Kuhfeld et al., 2020) and other testing organizations showed that student performance during the pandemic was consistent with prior school years in reading but not in mathematics where there was a noticeable decline. By spring of 2021, students' performance showed declines in both reading and mathematics. In addition, students in elementary grade levels registered more loss in mathematics than what was observed for students in middle grades. These reports however, did not focus on the different domains of mathematics to investigate whether the declines in mathematics performance were as a result of uniform declines in all the domains that were tested at grade level or whether there was a differential performance in the domain. This study seeks to explore if different domains of mathematics were affected differently.

Teaching must move with time and circumstances. Since learning has been disrupted by the pandemic, teachers must be highly adaptive, and data driven. Chang-Bacon (2021) highlighted that the academic success during the pandemic and beyond can be measured through the adjustments schools are making and how these adjustments are affecting learning. Unfortunately, schools and teachers either have no access to data that is useful for decision making or have insufficient data literacy. Adapting to the teaching of Students with Interrupted Formal Education (SIFE) also calls for data-driven professional development. Being quite new to the effects of this pandemic, there is not much research on recovery teaching for SIFE. This study gives the data and tools for professional developers, teachers, and policy makers to continue addressing the math learning loss. The results will also be instrumental in driving policy and helping educators use any available resources from the already depleted resources that many school districts have to target instruction for recovery efforts towards those domains.

Literature Review

The term SIFE in the US has historically been associated with immigrants with limited English proficiency who have had limited formal schooling and are at risk of failing (Costodio & O'Loughlin, 2020, DeCapua, & Marshall, 2011). Hos (2020, p.1022) wrote that "SIFE are students who speak an additional language(s), have entered a U.S. school after second grade, and function at least 2 years below their peers in reading and mathematics." This perspective is also reflected in interventions for SIFE in the US. For example, the New York State Education Department requires that students must first be identified as an English Language Learner before they can be identified as a SIFE.

Significant interruptions to formal schooling are caused by several factors and the effects of learning loss are not limited to immigrants with limited English proficiency. Research has shown that interruptions due to school closures lead to learning loss. For example, closing school for 20 days in one year was associated with lower performance in mathematics. Marcotte and Hemelt (2008) reported that school closure due to snow in Maryland was associated with a reduced number of students with satisfactory performance in math for up to 3%. Similar results were found after school interruptions due to the EBOLA outbreak (Bakrania et al., 2020) and the earthquake in Pakistan (Andrabi, Daniels, & Das, 2021). Significant interruptions can also be due to being put in juvenile justice facilities (Kubek, Tindall-Biggins, Reed, Carr, & Fenning, 2020), chronic health issues, housing instability, or school closures due to extreme weather (Conto, et. al, 2020).

Thus, this study moves away from the traditional notions that view SIFE as only students who migrated to the US after second grade and are identified as English Language Learners. Rather, we simply conceptualize SIFE as students who have had significant interruptions to their formal schooling. It is within this framing of SIFE that Chang-Bacon (2021) demonstrated that COVID-19 has caused interruptions to formal schooling for many learners creating a generation of SIFE that are not necessarily immigrants to the US or English Language Learners.

Empirical studies on interruptions to formal schooling and learning loss are very scarce (Conto, et. al, 2020). While we can learn a lot from research reports about SIFE who are immigrant ELLs (Chang-Bacon, 2021), the predictions of the effects of school closures on numeracy (Conto et. al., 2021), more empirical studies are needed. For this new generation of SIFE due to COVID-19, Betebenner and Wenning (2021) calls for evidence-based studies that identify the learning loss and how it may be addressed using the following key questions: 1) Who needs help? 2) What do they need help in? 3) How much help do they need?

In an attempt to identify subgroups of students that need help, Store et al. (2022) indicated that low socio-economic students, students of color and students who were not performing well before the pandemic have been hugely impacted by the pandemic.

Data and Methods

This study explores mathematics learning loss for 48 school districts in grades 3-5. All 48 school districts used in this study administer fall and spring Northwest Evaluation Association (NWEA) benchmark mathematics tests to their students in grades 3-5. However, due to the COVID-19 pandemic, they did not administer spring tests in the spring of 2020. In addition, assessment participation rates for spring 2021 were not as high as prior years. Therefore, this study used fall assessment data for three school years – two years before the COVID-19 pandemic (using 2018-2019 and 2019-20 data) and then assessing if the performance was different in the fall of 2020-21 (the COVID-19 pandemic school year).

The overall performance of students in mathematics before and during the COVID-19 pandemic has been discussed to a great extent. However, the performance of students in different domains has not been fully explored. Since we already know that there are declines in overall mathematics performance during the pandemic, this study will specifically examine the following questions:

1. Are students' experiencing declines in mathematics performance across all mathematics domains within grade levels?
2. Which specific grade levels and domains are of high concern?

In order to answer these questions, the study will use mean score performances and analysis of variance (ANOVA) of student Rasch Unit (RIT) scores to see if the performances pre-pandemic differ significantly from those during the pandemic. In addition to analyzing the overall performance on all domains tested per grade, each domain and grade level will be analyzed separately highlighting mathematics domains in grades 3-5. In all three grade levels (grades 3, 4 and 5), the following four domains of mathematics are tested on NWEA assessments: 1) Operations and algebraic thinking (OA), 2) number and operations (NO), 3) measurement and data (MD), and 4) geometry.

Results

Table 1 shows overall math performance and performance in different mathematics domains in grade 3 for 2018-19, 2019-2020 and 2020-2021 school years. The mean performance in all four domains and overall performance is lower for 2020-2021 school year (during the COVID-19 pandemic) than it was in 2018-2019 and 2019-2020 school years (prior to the pandemic). An in-depth analysis using one-way ANOVA on the performance in all four domains shows that the performance in grade three is significantly lower than it was in prior years on three of the four domains – Operations and algebraic thinking, number and operations, and geometry. However, there was no significant difference in performance on measurement and data where the F-statistic is 2.533, $p = 0.079$). As a result, overall mathematics performance in 2020-2021 school year is lower than the performance in prior years due to the declines in performance in these three domains. In addition, post hoc analysis using Student-Newman-Keuls and Tukey HSD confirm that while performances in the three domains and overall were similar in 2018-2019 and 2019-2020 school years, 2020-2021 math performance in the three domains and overall were different to those from two prior years.

Table 1

Overall and Domain Performance for Grade Three

	2018-2019			2019-2020			2020-2021		
Domain	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
OA	2394	187.3	15.2	2457	187.1	15.5	2233	180.3	17.8
NO	2394	186.6	14.5	2457	186.1	14.4	2233	184.0	17.1
MD	2394	186.6	15.2	2457	185.9	15.0	2233	185.6	16.1
Geometry	2394	188.3	15.5	2457	188.1	15.1	2233	187.1	16.4
Overall	2394	187.2	13.7	2457	186.8	13.6	2233	184.2	14.7

For grade four, the mean overall math performance and performance in different mathematics domains for 2018-19, 2019-2020, displayed in table 2, were higher than those of 2020-2021. In addition, a one-way ANOVA on the performance in all four domains shows that the performance in grade four in 2020-21 is significantly lower than it was in prior years on all four domains of mathematics. F-statistic values in all domains and overall performance ranged from 33.106 to 55.115 with $p < 0.001$ in all cases. This implies that the overall decline in mathematics performance in 2020-2021 school year is not due to one or a couple of mathematics domains – all four domains are significantly affected. Further, post hoc analysis using Student-Newman-Keuls and Tukey HSD confirm that the performance in 2018-2019 and 2019-2020 school years are similar in all four domains and overall performance. However, overall math performance and performance in each of the four domains for 2020-2021 school year was significantly different from prior two school years.

Table 2

Overall and Domain Performance for Grade Four

	2018-2019			2019-2020			2020-2021		
Domain	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
OA	2232	198.8	15.4	2389	198.6	15.8	2297	194.3	18.3
NO	2232	197.4	14.4	2389	197.5	15.0	2297	194.2	17.0
MD	2232	197.0	16.0	2389	196.5	15.9	2297	193.3	16.7
Geometry	2232	198.3	15.7	2389	198.5	15.7	2297	194.7	14.9
Overall	2232	197.9	14.1	2389	197.8	14.4	2297	194.1	14.8

Similarly, the mean overall math performance and performance in different mathematics domains for 2018-19, 2019-2020, displayed in table 3, were higher than those of 2020-2021 school year in grade 5. Also, a one-way ANOVA on the performance in all four domains shows that the performance in 2020-2021 for grade five is significantly lower than it was in prior years on all four domains – Operations and algebraic thinking, number and operations, measurement and data, and geometry. F-statistic values in all domains and overall performance ranged from 6.014 ($p < 0.002$) for number and operations to 92.433 ($p < 0.001$) in geometry. Again, the overall decline in mathematics performance in 2020-2021 school year is due to declines in all of the four mathematics domains that are tested as all four domains are significantly affected. Further post hoc analysis using Student-Newman-Keuls and Tukey HSD confirm that the performance in 2018-2019 and 2019-2020 school years are similar in all four domains and overall performance. However, overall math performance and performance in each of the four domains for 2020-2021 school year was different from prior two school years. It is important to note that while Student-Newman-Keuls considers the performance in number and operations between 2019-2020 and 2020-2021 to be significantly different, Tukey HSD finds that performance not different.

Table 3

Overall and Domain Performance for Grade Five

	2018-2019			2019-2020			2020-2021		
Domain	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
OA	2252	207.6	16.2	2230	206.7	16.2	2166	203.9	17.4
NO	2252	208.0	16.6	2230	207.3	16.8	2166	206.3	18.0
MD	2252	206.2	17.7	2230	205.2	17.4	2166	202.1	17.9
Geometry	2252	207.9	16.6	2230	207.3	16.9	2166	201.7	16.5
Overall	2252	207.4	15.7	2230	206.6	15.7	2166	203.5	15.8

Discussion

Using the definition of SIFE as students whose formal schooling has been significantly interrupted, the study sought to identify the grade bands of students who have shown significant decline in mathematics performance. It also sought to identify the NWEA's mathematical domains whose performance declined during the COVID-19 school interruption. In grade three, the effects of the pandemic are seen in operations and algebraic thinking, number and operations, geometry but not in measurement and data. However, performance declined in both fourth and fifth grade mathematics is in all domains. It is important to not overgeneralize and correlate the trend of the decline with increase grade levels. Further analysis for data, not included in this paper, showed that only grade 4 to 6 had declines in all domains. Grades 7 and 8 had declines in some domains but not all.

While other researchers have addressed part of the framework for this study on identifying who needs help, this study has established that students need help in almost all of the domains in mathematics in grades 3-5. The study provides significant information on the domains which policy makers, educators, and other stakeholders need to focus on and put more resources to improve mathematics performance. As we address the needs of SIFE whose school interruption is due to COVID-19, it is important to acknowledge that resources in the field of education for SIFE already exist (Freeman & Freeman, 2002). Lessons from and resources for educating SIFE including those experiencing housing insecurities, natural disasters, punitive suspensions, incarceration, or chronic health issues can be repurposed to address interruptions due to the COVID-19 pandemic (Chang-Bacon, 2021, Schilling & Getch, 2018).

In exploring the mathematics performance of SIFE due to COVID-19, this study has not analyzed the data for different demographic groups. In a predictive study of the effects of school interruptions due to COVID-19 that was based on data from 174 countries, Azevedo (2021, p.1) wrote that "Exclusion and inequality will likely be exacerbated if already marginalized and vulnerable groups, such as girls, ethnic minorities, and persons with disabilities, are more adversely affected by school closures". This is consistent with Store et.al (2022) findings that have been discussed already. However, more studies need to be done using newer data to examine if the gaps in performance between students of different demographic backgrounds are getting better or if they are getting wider.

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COREQUISITE QUANTITATIVE REASONING: A SUCCESSFUL ALTERNATIVE TO REMEDIATION

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Corequisite courses combine developmental material within credit-bearing courses. Such courses offer a more efficient path to college-level coursework for academically underprepared college students, who tend to come from historically marginalized populations. Data from a dual-mission, open-enrollment institution suggest students who enroll in a single-semester corequisite quantitative reasoning course are more likely to satisfy a state mandated quantitative literacy requirement within two years than their peers who enroll in a two-course, developmental-to-credit-bearing series. Combined program completion/retention rates and pass rates are statistically similar for both pathways, which indicates the corequisite course is doing no harm academically while saving students tuition costs.

Background and Literature Review

Developmental courses, which were initially designed to increase college access for academically underprepared college students, do not appear to be fulfilling their mission. Students who arrive at college in need of remediation are less likely to persist through college-level, credit-bearing courses and are less likely to complete their program of study (Edgecombe et al., 2013). The demographics of students who enroll in developmental courses show they are disproportionately populated by historically disenfranchised students: students of color, older adults, first-generation students, and those from low-income backgrounds (Ganga et al., 2018). Yet there is a clear need for remediation in institutions of higher education. Almost 40% of students who begin their postsecondary academic career at public four-year institutions and 68% of students who begin at public two-year institutions take at least one developmental course. About 1 in 3 students starting at public four-year colleges and about 3 in 5 students starting at public two-year institutions take at least one developmental mathematics course (Chen, 2016). Unfortunately, the pipeline from developmental mathematics courses to credit bearing mathematics courses is leaky, with just 11% of students who need more than three levels of mathematics remediation persisting to a credit-bearing mathematics course. The remaining 89% of students attrit at various levels, either because they do not pass a course or because they fail to enroll in a subsequent course (Jaggars & Stacey, 2014). For the reasons mentioned above, developmental mathematics courses can be a significant roadblock for retention, persistence, and program completion.

Research points to corequisite courses as a promising development that meets academically underprepared college students where they are while simultaneously improving academic outcomes. Corequisite courses are designed to provide remediation within or parallel to credit-bearing courses. The structure and content of the courses vary but many models embed additional academic and/or nonacademic supports into the curriculum (Logue et al., 2016, 2019). Preliminary research showed successful completion of corequisite mathematics courses can increase persistence, retention (Rutschow, 2019), and degree or certificate completion (Logue et al., 2019).

Institutional Demographics

Our institution is a comprehensive public, dual-mission university located in the intermountain west that serves 19,000 degree-seeking students with an additional 10,000 concurrent enrollment students. The demographics of the degree-seeking students reflect the institution's dual focus: the average age of an undergraduate is 26 years, and the students are more likely to be first-generation college students than their peers at other regional universities. About 25% of the student body identify as minority students, and the 6-year graduation rate for all students was almost 35% in 2018 (Weber State University, 2019). A higher percentage are married, have children, are working full time, receive financial aid, and need remediation in math or English as compared to students attending similar institutions (Weber State University, 2019).

Students at our institution who require the most intensive remediation must enroll in up to two developmental English courses and up to three developmental mathematics courses. This can lengthen their time to graduation by a year or more and cost up to 19 credit hours of tuition and fees that do not count toward degree completion. Prior to implementation of the corequisite quantitative literacy course, who placed one level below the credit-bearing quantitative literacy course were required to take a five-credit developmental mathematics course followed by a three-credit credit-bearing quantitative literacy course. The additional time and money required by enrolling in developmental courses is especially problematic as these students are often the institution's most vulnerable, falling into one or more of the highest risk categories for not persisting: low-income, first generation, nontraditional, and/or minority. Implementation of our corequisite quantitative literacy course offered a path to a credit-bearing, QL-satisfying course in a single semester and reduced tuition costs by two credits for a portion of our developmental students.

Impetus for Course Development

Consistent with research, we found the pathway from developmental mathematics courses to credit-bearing mathematics courses to be porous at our institution. State requirements mandate students fulfill a quantitative literacy (QL) requirement prior to being awarded a bachelor's degree. While there are many means available to satisfy the QL requirement, research from our institution has found that 65% of graduating students could satisfy QL by taking a quantitative reasoning course rather than an algebra-based course (college algebra, calculus, etc.) or an introductory statistics course.

We were tasked by the provost's office at our institution to create a corequisite quantitative literacy course to provide an alternate, more streamlined approach for students to satisfy their QL requirement. While developing the corequisite course, we seized the opportunity to reevaluate both the underlying pedagogy and the content in a quantitative literacy course. Students, especially historically disenfranchised students, are better served by pedagogies that foreground faculty-student interactions, power sharing, dialogic student-professor interactions, activation of student voice, and utilization of personal narratives that cumulatively "embrace the whole student in the learning process" (Tuitt, 2003, p. 243) rather than the traditional lecture format. To that end, the guiding principle behind the course design was building a curriculum that rested upon concepts students can readily use when they walk out of the class into the real world and implementing a pedagogy that forefronts students' existing experiences and knowledge. Within this framework we employed a just-in-time approach to the delivery of prerequisite material

Research Questions

This study compares course pass rates, retention and /or degree or certificate attainment, and length of time to fulfill the QL requirement for students who chose to take an eight credit, two-course, developmental-to-credit-bearing series to fulfill their QL requirement to students who take a one-course, six-credit corequisite quantitative literacy course to fulfill their QL requirement. Thus, the three research questions guiding this study are:

- How do pass rates for students who enroll in the developmental course of the two-course series compare to that of students who enroll in the corequisite course?

- How do QL fulfillment rates within one and two years of enrolling in the developmental course in the two-course series compare to that of students who enroll in the corequisite course?
- How do retention and/or degree or certificate completion rates for students in the developmental course of the two-course series compare to that of students who enroll in the corequisite course?

Pass rates were defined as the proportion of students who earn a C or greater in the course. Retention rates were consistent with the standard at our institution; namely a student is retained if they are enrolled in courses one year following their enrollment in either the developmental course of interest or the corequisite quantitative literacy course. Students who earned a degree or certificate within one year of enrolling in the course of interest were grouped with students who were retained.

Participants

Participants of this study were enrolled in either the corequisite quantitative literacy course or the developmental course of the two-course quantitative literacy sequence between Spring 2019 and Summer 2021. During the timeframe of this study, the corequisite quantitative literacy course had experimental status at the institution. Among other things, this designation meant an override from the mathematics department was required to enroll in the course. The students recruited to enroll in the corequisite course primarily fell into two classifications. One group of students were in their second semester of college, having been admitted to the university with placement in both developmental English and developmental mathematics. The second group of students had completed at least 75% of the requirements for their program of study but had yet to fulfill their quantitative literacy requirement. Because of the relatively small sample size, we did not differentiate between the two groups in our final analyses. There were no special recruitment efforts made for the students who enrolled in the developmental course.

Methods & Results

This study examined the performance of students who enrolled in the corequisite QL course as compared to the performance of students who enrolled in the developmental course of the two-course series during the same semesters. Eleven sections of the corequisite QL course have been offered over five semesters (Spring 2019 through Summer 2021) comprising 256 students. During those same five semesters, 54 sections of the developmental course were offered, comprising 1084 students. De-identified data was obtained through the university's Office of Institutional Effectiveness.

Table 1 summarizes the pass rates, measured as the proportion of enrolled students who earned a grade of C or higher, for both the corequisite QL course and the developmental course of the two-course series by semester.

Table 1

Summary of Comparative Pass Rates

Semester	Corequisite Course		Developmental Course		
	Enrollment (sections)	Pass Rate	Enrollment (sections)	Pass Rate	p-value
Spring 2019	28 (1)	75.0%	263 (13)	65.8%	.325
Spring 2020	63 (3)	84.1%	268 (13)	79.1%	.369
Fall 2020	24 (1)	91.7%	251 (13)	79.3%	.145
Spring 2021	97 (4)	81.4%	234 (11)	77.4%	.409
Summer 2021	44 (2)	93.2%	68 (4)	83.8%	.144
Total	256 (11)	84.4%	1084 (54)	75.8%	.003**

**p <.01

As shown in Table 1, the pass rates were higher in the corequisite QL course than the developmental course of the two-course sequence in each semester. While the overall pass rate is substantially higher for the corequisite QL course than the development course, the differences for each semester, as calculated using two-proportion Z tests, are not statistically significant.

Ideally, students who enroll in the developmental course would enroll in the QL-bearing course the following semester. Table 2 shows the proportion of students that successfully satisfied the university's QL requirement within one or two years of enrolling in either the corequisite QL course or the developmental course.

Table 2

Percent of Students Who Earned QL Within One and Two Years by Course

Semester	Corequisite		Developmental		
	Enrollment	% QL Satisfied	Enrollment	% QL Satisfied	
		Within One Year [a]		Within One Year	Within Two Years [b]
Spring 2019	28	75.0%	263	6.5%***	41.1%***
Spring 2020	63	84.1%	268	18.3%***	50.7%***
Fall 2020	24	91.7%	251	43.0%***	N/A

Note. [a] There were no students who did not pass the corequisite QL course that subsequently satisfied the QL requirement within two years, thus the pass rate is equivalent to the QL satisfaction proportions for both one and two years.
[b] There were students who did not pass the developmental course but were able to satisfy the QL requirement within two years.
***p <.001

As can be seen in Table 2, students who took the corequisite course were much more likely to satisfy the QL requirement within one year than students who enrolled in the two-course series. A portion of this success is inherent in a single-course model, which eliminates the possibility of attrition between a developmental course and a credit-bearing, QL-satisfying course. Two-proportion Z tests were performed to compare the QL satisfaction rates for the students who enrolled in the corequisite QL course to the QL satisfaction rates within one and two years for the students who enrolled in the developmental course. In every case the difference was highly statistically significant (p-value < .001).

To assess retention, the status of students was determined for the semester one year after enrolling in either the corequisite QL course or one year after enrolling in the developmental course. Students were classified as obtaining a degree if they completed a degree or certificate program. Students who did not obtain a degree or certificate but were enrolled at the institution the following year were classified as retained. This information is summarized in Table 3.

Table 3

Persistence of Students by Course

Semester	Corequisite		Developmental		
	Enrollment	Degree or retained	Enrollment	Degree or retained	p-value
Spring 2019	28	82%	263	73%	.246
Spring 2020	63	73%	268	77%	.516
Fall 2020	24	79%	251	73%	.494
Total	115	77%	782	75%	.635

Note. None of the results were statistically significant at p<.1

As illustrated in Table 3, 77% of the students who enrolled in the corequisite course were either retained or completed a program as compared to 75% of students who enrolled in the first course of the two-course series. If success is measured by either certificate or degree completion or retention, two-proportion Z tests indicate there is not a statistically significant difference for enrolling in either course. However, there is an argument to be made for the positive impact the corequisite course has on students who avoided or failed in their attempts to satisfy QL, which will be discussed presently.

Discussion and Implications

Research shows that students who arrive at college academically underprepared are less likely to persist, be retained, or complete a program of study. Our preliminary results reveal that students who enroll in our corequisite course are more likely to satisfy a state mandated quantitative literacy requirement sooner than students who take a two-course developmental-to-credit-bearing sequence. Many of the students who enrolled in the corequisite course are vulnerable as they are members of underserved populations, academically underprepared, had failed to satisfy the QL requirement, and/or had avoided taking classes towards satisfying the QL requirement. That there is no statistical difference in pass rates or retention and/or degree or certificate completion rates for students who enroll in the corequisite course and students who enrolled in the developmental course illustrates the corequisite course is, at the worst, doing no harm. In fact, it could be argued that the corequisite course has aided a portion of students in completing their program of study who may not otherwise may not have.

The corequisite quantitative literacy course became a permanent course in Fall 2021. As a result, the course will be widely available to those who wish to enroll. With increasing enrollment, we hope to expand our research efforts to differentiate outcomes for students who are early in their college career from those who close to completing their program of study, investigate if the corequisite course impacts students' attitudes towards mathematics, and explore factors that may influence degree-seeking persistence, especially for students who have been historically disenfranchised. It is the hope of the institution that by encouraging students to satisfy QL early in their academic careers via a corequisite course students will save time and money by reducing the number of repeated courses and delays associated with avoiding mathematics courses.

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PARENTS AS FACILITATORS: UTILIZATION OF BILINGUAL LANGUAGING PRACTICES DURING MATHEMATICAL PROBLEM SOLVING

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This study highlights parents' linguistic capital and how they use specific languaging practices to facilitate their child's learning. One bilingual family used multiple languages to facilitate their son's learning through two mathematical tasks. Using Dominguez' conceptual framework of bilingualism, we analyzed these conversations to look for natural units of communication and its relation towards their problem solving goals. The data shows the family would switch from English to Spanish to help their child surpass several barriers during their mathematical activities. Leveraging bilingual languaging practices can counter the deficit lens with which minoritized students are typically viewed.

Introduction and Relevant Literature

Much has been explored regarding the relationship between school-based learning and out-of-school contexts; establishing a unidirectional path where content learned in school is expected to be applied outside of school contexts (Dominguez, 2011). This study contributes to the growing body of literature pushing against this relationship by recognizing and valuing bilingual languaging practices in families as they use their linguistic capital to solve mathematics problems. Previous research broadly focuses on bilingualism's relationship to mathematical learning from the student's perspective. For example, multilingual students achieve higher levels of meaning making when mathematical problems incorporate their home language (Erath et al., 2021), while others utilize language switching, recalling their specific language of instruction to help them solve mathematical problems. (Moschkovich, 2007).

Language switching involves utilizing two (or more) languages during mental arithmetic computation (Moschkovic, 2007). For bilingual learners, they each have a preferred language for conducting arithmetic computation, with the preferred language being the one utilized for their instruction (Moschkovic, 2007; Edmonds-Wathen et al., 2019). When confronted with a novel mathematics problem in their second language, bilingual learners will language switch in an attempt to make sense of the task (Moschkovicz, 2007). While this phenomenon is well explored from the student's perspective, fewer studies have been conducted on how parents and guardians utilize these same strategies.

Through our work, we look at a family's languaging practices occurring as parents fulfill a facilitator role during their children's mathematical work. Previous research on parental involvement has highlighted the overall desire for parents and guardians to fulfill a facilitator role (Civil & Bernier, 2006; Harper et al., 2021). While acting as facilitators, bilingual parents and guardians use language switching to help scaffold their children's learning. For example, Willey and Morales (2020) demonstrated how parents participating in a dual language after school mathematics program with their children frequently re-shaped the linguistic landscape by pushing for the usage of their primary language (Spanish), despite the social pressures to use their second (English). This helped establish new norms allowing for more languaging practices to be used in mathematical problem solving (Willey & Morales, 2020).

The objective of this study is to explore how families make sense of mathematical problems using their linguistic capital via a case study of one family's experience working through activities as a unit at a family mathematics event. By recognizing and leveraging their linguistic capital as bilinguals, parents and guardians can be recognized and involved in their children's education as facilitators. In turn, positive attitudes towards school can be created, countering the typically deleterious consequences of traditional school curriculum that continually views students of color with a deficit lens (Pinedo et al., 2021).

Conceptual Framework

We follow Dominguez's (2011) conceptualization of bilingualism as "cognitive resources for solving school based mathematical problems" (p. 307). It is imperative that bilingualism be seen as an asset, and subsequently leveraged to its fullest extent. This includes the assets found at home, as parents fulfill their roles as facilitators and use their own linguistic capital to help out their children when prompted. In addition, we also draw from Yosso's (2005) model of community cultural wealth, which includes various forms of capital minoritized students bring with them into the classroom. Among them, we focus on linguistic capital which includes cultural knowledge among family members and their communication skills in more than one language (Yosso, 2005). As a result, bilingualism is further defined as a social action, incorporating all forms of communicative practices with and to others that converge towards meaning making (Dominguez, 2011).

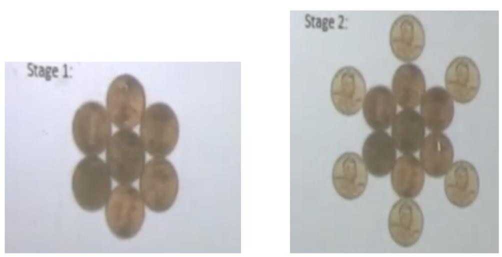
Methods

For this paper, we focus on the Rodriguez (pseudonym) family and their languaging practices while facilitating their son's mathematics activities during two mathematical tasks. The Rodriguez family participated in a mathematics event held before a summer school program for parents and guardians to get a richer understanding of the mathematics activities students would do during the program. We focus our efforts on one of their assigned activities; a visual growth pattern task (see Figure 1). In this task, participants are asked to predict the number of pennies in several stages according to the visual growth pattern as shown in the first two stages. Based on these predictions, participants conclude this assignment by developing their own algorithm for determining the number of pennies at any stage.

Figure 1

Visual growth pattern task given to families to work on together.

Cecilia is playing with a jar full of pennies. Stage 1 of her design shows 1 penny surrounded by 6 additional pennies. To create each additional stage, she placed more pennies extending out from the six. Stage two is also shown



If the pattern continues, how many pennies does Cecilia need for stage 3?
If the pattern continues, how many pennies does Cecilia need for stage 10? 100?
Is there a way to determine the number of pennies Cecilia needs for any stage? How?
What algorithm or steps can be followed to get the number of pennies for any stage?

Context and Data Collection

A summer mathematics institute was organized by our research team for rising fourth and fifth graders at an elementary school in central Texas. The overall goal of this institute was to enhance students' confidence in mathematics via a series of projects designed to encourage participation and increase the visibility of mathematics in their day to day lives. Alongside this institute, a family mathematics event was conducted to give parents and guardians an opportunity to become familiar with the kind of work their children would be doing at the institute. Consent forms were given to these family members to opt-in to the video and audio recorded segments of the family event.

Among the families opting in to the study, the Rodriguez family stood out due to their bilingual languaging practices used while working on the assigned activities. As shown above, the visual growth pattern assignment was written exclusively in English, and the mathematics event facilitators conducted these sessions in English. In spite of this limitation, the Rodriguez family used the Spanish language during their problem solving process. Their decisions to language switch at key intervals during their session was entirely their own. As a result, this paper focuses on the Rodriguez' mathematical languaging practices as they became facilitators to their child's mathematical learning.

Data Analysis

Audio transcripts were separated into two episodes of mathematical activity; one for each mathematical task facilitated by the Rodriguez family. These transcripts were analyzed to underscore languaging practices during each episode. Following our bilingualism framework, the transcripts were coded for natural units of communication, or individual units of conversation oriented towards solving a problem (Dominguez, 2011). Similar to Dominguez, we focus solely on verbal units of communication. Verbal units of conversation were then coded as either reinvention actions or reproduction actions. Reinvention actions are meaning making actions housed within the unique languaging practices of the family as a unit. Reproduction actions include students' predispositions to follow a formulaic path to an answer, which could often be incomplete or incorrect (Dominguez, 2011; examples below in results). Each unit of communication was categorized into these codes individually by our research collective. In addition, themes were generated for parents which highlighted their specific contributions towards reproduction and/or reinvention actions. These themes serve as the focal point of our data, serving to illustrate parents' contributions towards sense making via their languaging practices. Following that, all researchers met to share codes and arrive at a consensus. Looking across the coded units established via the research collective, patterns emerged in the Rodriguez family's usage of their linguistic capital.

Results

We use the data excerpt below to highlight the languaging practices occurring throughout the Rodriguez' problem solving session. The excerpt is from the conversation between the learner and his parents as they work through the visual growth pattern task. Initially, the learner (marked as student) goes through a series of reproduction actions, where he relies on his previous knowledge to follow a formulaic path to an answer. When this fails, the parents tap into their linguistic capital to help facilitate the problem solving process. With that, the learner then goes through a series of reinvention actions, clarifying the prompts and allowing the learner to continue through the assignment.

1. Parents: Leele ahi, que dice?
2. Student: Dice, it says Cecilia is playing a jar full of pennies. Stage one of her design shows one penny surrounded by six additional pennies. To create each additional stage, she placed more pennies… if the pattern continues… six more, I know that's seven. Six equals thirteen.
3. S: How many pennies does Cecilia have for stage three. Since this is stage two, add nine… Nineteen.
4. P: Ok. Why?
5. S: Cause, even plus six equals thirteen. I know that three plus six equals nine. The ten left, plus nine, nineteen.
6. S: So if the pattern continues, how many pennies does Cecilia need for stage ten. Wait, what does it mean right here?
7. P: Ok, so this is stage three right? Nineteen, so
8. S: ten? Stage ten…
9. P: How many you think? Okay so…
10. S: If I multiply, six, I can take the one in the middle, since it says six, six times ten equals sixty, plus one we took off, sixty one
11. S: But why does it say this? It's a mistake?
12. P: Don't worry about it
13. S: Is there… is there a way to determine the number of pennies Cecilia needs for any stage? (Repeats). How, what does it mean?
14. P: Think about it
15. S: I still don't know what does determine? Wait
16. P: Determinar
17. S: Wait, is there a way to determine the number of pennies Cecilia needs for any stage
18. S: I didn't get it
19. P: Que dice?
20. S: That it says, is there a way to determine the number of pennies Cecilia needs for any stage
21. P: Ahorita lo acabas de hacer aquí. Cuantos ocupamos?

Rodriguez' use of linguistic capital

The Rodriguez parents' expansive languaging practices came at key moments during the assignment. For example, at lines 15 and 16, the parents' use of language switching to Spanish to translate a word allowed the learner to proceed to the next part of the task. Although simple at first glance, we would like to emphasize that translating the word "determine" into Spanish was a deliberate choice on behalf of the parents. By providing the word in Spanish, the child was given opportunities to use their linguistic capital to overcome language barriers and have an understanding of what the mathematical task was asking. Using Spanish as a resource allowed the confusion to be clarified and the learner was able to proceed. This indicates that the parents knew about the value of language switching, and opted to use this tactic when needed.

Parents' role during moments of reproduction and reinvention

At lines 3-5, we see the learners' predispositions towards reproducing procedures, in this case addition and subtraction. The learner recognizes, according to the images, six more pennies are added per stage. Following that, he deduces adding the number six to each stage should give the answer to the number of pennies per stage. Even though the learner was able to reproduce addition procedures, he failed to recognize a consistent pattern or algorithm across the stages. This obstacle eventually halts progress on the task altogether, as the learner reads and rereads the prompts to try to find his way back toward making progress. This is an example of the limitations of reproductive actions in which students follow algorithms without having a conceptual understanding for why they work. In this instance, the student used the algorithm but was not able to recognize why it failed.

To move past these obstacles created by reproduction actions, the learner needs to deviate from established norms and reconsider the questions through a different perspective. This opens up space for reinvention actions, involving different languaging practices leading to sense-making. As seen in lines 20 and 21, the learner was unable to proceed through the part of the task asking the learner to generalize the pattern. His reproduction actions enabled him to predict the number of pennies per stage, yet insufficient to confirm a pattern or algorithm. Noticeably, the parents initiated a reinvention action by language switching and explaining how he could approach solving the problem. The need for language switching was indicative of a language barrier enhancing the difficulty for the learner to proceed through each question. The parents recognized this, and subsequently would language switch to Spanish to explain each prompt in a way they knew their child understood. Sometimes translating a word would suffice (lines 15-16), while other questions required a deeper explanation to yield the same result (lines 20-21).

Discussion and Conclusion

Through the excerpt shown above, we give a brief glimpse of language switching and how it was utilized by the Rodriguez parents in their facilitator roles, and how they tapped into their linguistic capital to facilitate their son's mathematical thinking. In doing so, the parents improved their ability to facilitate mathematical learning which led to an improved performance on behalf of the student. These findings align with Yosso's (2005) community cultural wealth model, which disrupts the typical deficit lens through which multilingual Students of Color are viewed. When confronted with a particularly challenging problem, parents tap into their knowledge across languages in an effort to help their child succeed. Collaborative activities, as seen in family mathematics events, provide an excellent example of work that validates and leverages the entirety of students' linguistic capital. Although our findings are limited to an out of school context, the end goal of creating a more inclusive learning environment that allows for language switching is equally applicable in classrooms as well.

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Moving Forward, Leaning in: Acceleration over Remediation For Teachers

MEASURING STUDENTS' STEM SMART SKILLS: STUDYING TEACHERS' BELIEFS

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In conversations with educators, we hear teachers discuss life skills and dispositions that help students succeed in learning mathematics. These student characteristics are separate from explicit content skills and knowledge. In our STEM learning study of non-academic skills, we are interested in the overlap between teachers' beliefs about what life skills and character traits are necessary for success and the empirical research about non-academic factors that contribute to students' success. This paper is a systematic review of literature on the research of K-12 educators and teacher educators' beliefs about non-academic skills and dispositions that support students' mathematics and science learning.

Introduction

Classroom teachers observe much more about their students than academic performance. Within the classroom context, teachers observe many non-academic aspects of students' dispositions and character traits. This paper investigates which *non-academic skills* teachers identify as critical for supporting students' learning in mathematics and other STEM fields. We look at research on teacher beliefs about this aspect of student development because we value teachers' experience, observations, insights, and knowledge about what non-academic skills, dispositions, and character traits correlate with students' learning and performance. Our systematic review of research literature uncovered five skill domains that teachers believe students need to master in order to be successful in STEM classes. These are "commonsense" life skills and dispositions, not typically taught in schools, that we incorporate into a "STEM Smart Skills" model (Suh et al., in press). This systematic review of the literature will be used to design a future mixed methods empirical study of teacher beliefs about *STEM Smart Skills*.

Theoretical Framework

Many years of educational research have supported the claim that teacher beliefs about students can influence student performance. Well-known prior research focuses on teacher beliefs in terms of whether teachers believe certain students are capable of high achievement and how those beliefs affect teachers' behavior toward students. However, this study focuses on different aspects of teacher beliefs: We wanted to look at what non-academic life skills and character traits teachers believe are linked to success in STEM fields. To situate our study within the literature, we surveyed the larger context of research on teacher beliefs. The vast majority of studies about teacher beliefs focus on how teacher beliefs affect teachers' behavior toward students and/or instructional innovation (Brophy & Good, 1986; Wang et al., 1993).

Methodology

Systematic reviews of research literature apply detailed, comprehensive analysis to identify, appraise, and synthesize studies and reduce bias (Denyer & Tranfield, 2009; Uman, 2011).

Data Collection: This study was conducted using a Google Scholar search with the key words *teachers*, *beliefs*, *STEM*, *student*, and *success* in a ten-year range from 2011 to 2021. Our first search yielded about 20,200 results. From this initial result, the first fifteen pages (150 items) were manually reviewed to select peer-reviewed articles matching our search criteria. Thus, articles that lacked one of the key terms within the summary or the paper were eliminated. For instance, a paper by De Angelis (2011) on teachers' beliefs about the role of prior language knowledge lacked discussion of STEM topics and, therefore, was not included. Other papers that used synonyms of our key words were added. For example, Nadelson et al.'s (2013) "Teacher STEM Perception and Preparation: Inquiry-Based STEM Professional Development for Elementary Teachers" used the word *perceptions* instead of *beliefs* and was added to our selected articles.

In this first review of the fifteen pages in Google Scholar, seven papers were found. Such papers were further examined in depth as snowball sampling, resulting in four additional articles. Finally, a double review of the first 15 pages of Google Scholar findings yielded an additional 13 articles for a total of 24 articles. Based on their focus, the papers were divided in four categories: teacher practices, literature review, teacher's beliefs about student's background, and learning outcomes. Seventeen articles were identified as teacher practices, one article was classified as literature review, five articles discussed teacher's beliefs about students' background, and one paper was classified as learning outcomes. (See Table 1).

Data Analysis: Articles matching the focus of the literature review were analyzed qualitatively to identify common themes across the literature related to what is currently known about STEM teacher and teacher educator beliefs about dispositions necessary for students' STEM learning.

Table 1
Review of the Literature

	Author Last Name (Year)	*Discipline*	*Grade Level*	*Teacher Practices*	*Literature Review*	*Teachers' Beliefs on Students*	*Learning Outcomes*
1	Archambault et al. (2012)	Mathematics	Secondary	X			
2	Barak (2014)	STEM	Pre-Service Teachers	X			
3	Blanchard et al. (2016)	Technology	Middle School	X			
4	Chrysostomou & Philippou (2010)	Mathematics	Primary School	X		X	
5	Copur-Gencturk et al. (2019)	Mathematics	K-8			X	
6	Dare et al. (2014)	Engineering & Physics	K-12	X		X	
7	Ebert-May et al. (2015)	STEM	College/ Graduate	X			
8	Edmondson (2019)	STEM	High School			X	
9	Lazarides & Watt (2015)	Mathematics	Grade 10			X	
10	Margot & Kettler (2019)	STEM	K-12		X	X	
11	Miranda & Russell (2012)	Technology	Elementary	X			
12	Nadelson et al. (2013)	STEM	Elementary	X			
13	Nathan et al. (2010)	Engineering	High School	X		X	
14	O' Neal et al. (2017)	Technology	K-12			X	
15	Park et al. (2017)	STEM	Early Childhood	X		X	
16	Park Rogers et al. (2011)	Mathematics & Science	K-12	X			
17	Pizdrowski et al. (2012)	Mathematics	High School	X		X	
18	Pryor et al. (2016)	STEM	Elem., Middle, High School	X			
19	Radloff &Guzey (2016)	STEM	College	X			
20	Smith et al. (2015)	STEM	Secondary	X			
21	Stohlmann et al. (2012)	STEM	Middle School	X			
22	Tofel-Grelh & Callahan (2017)	STEM	High School			X	
23	Van Haneghan et al. (2015)	Engineering	Middle School				X
24	Wang et al. (2011)	STEM	Middle School	X			

The authors applied thematic analysis (Braun & Clarke, 2012), a rigorous qualitative method involving the establishment of analytic categories and their provisional definitions in six phases: (1) Familiarization through multiple readings of the data, (2) Formulation of initial codes by identifying common themes and novel trends, (3) Search for themes by reviewing coded segments and generalizability to a larger section of the data, (4) Review of potential themes by comparing across coded segments, and (5) Definition and naming of themes and establishing theme boundaries.

After defining and naming the themes, we calculated the number of utterances (or times the theme was referenced in the literature) and selected a quote from the literature to represent that particular belief about necessary dispositions. In our calculations of the count data, a single phrase could be counted multiple times if it related to multiple codes. For example, "All three teachers...believe that problem solving plays an important role in integrating engineering into science and mathematics" (Wang et al., 2011, p. 10) was coded as both *STEM for All* and *Promoting Persistence*. In this way, this single quote yielded two utterances.

Results from Systematic Review of the Literature

The analysis yielded five overarching themes related to teachers' beliefs about necessary dispositions for STEM learning. Qualitative and frequency count data from each of the emerging themes is presented below.

1. Encouraging Academic Risk Taking: In the literature, *Academic Risk Taking* was the most frequently referenced skill. A total of 60 utterances were coded as *Academic Risk Taking* and were further divided into three subthemes related to students' success in STEM (Table 2). Overall, risk taking in the literature included encouraging students to become self-directed and to solve problems through inquiry. Teachers also believed that it was important to encourage Cooperative and intrinsically motivated learning. The theme of *Risk Taking* encompassed three subthemes.

Table 2
Examples of Encouraging Academic Risk Taking in the Literature

Subtheme	Example Quote
Give Time and Space (37)	"His view that scientific inquiry in the classroom can only if the students are fully in charge of designing and implementing an investigation" (Park Rogers et al., 2010, p. 906)
Encourage Questioning (14)	"The purpose of the motivating and engaging context provides students with real problems that require them to draw from multiple disciplines in order to solve a given problem or challenge" (Dare et al., 2014, p. 2)

Support Wonder (9)	"Capitalizing on the enthusiasm of young learners and their desire to explore STEM concepts, the development of student foundational STEM knowledge, and flexibility in the elementary curriculum that can more readily support innovative approaches for teaching STEM content" (Nadelson et al., 2013, p. 157)

2. Making STEM Accessible for All and Viewing STEM as Interdisciplinary: We conceptualized the theme *STEM for All and All Things as STEM* as emphasizing the interdisciplinary nature of STEM as learning that can occur in multiple environments and the importance of making STEM accessible for all. Within our data, we identified 44 utterances, separated into three subthemes which fell within this theme. The subtheme integrated disciplines of STEM was the most common theme (Table 3).

Table 3
Examples of STEM for All and All Things as STEM in the Literature

Subtheme	Example Quote
All Types of STEM (Integrated Disciplines) (25)	"All three teachers believed that science, mathematics, and engineering are related in a very natural way, either by content or problem solving processes " (Wang et al., 2011, p. 10)
All Types of Students (16)	"[Teachers held the epistemological belief that] If a student is *not* naturally gifted in mathematics, they can still learn the class materials well" (Chrysostomou & Philippou, 2010, p. 1512)
All Types of Learning Environments (3)	"Connection between in-school and out-of-school learning" (Nathan et al., 2009, p. 14)

3. Embracing Mistakes as Learning Moments: The literature contained several references to how STEM teachers believed that mistakes should be seen as learning opportunities. Teachers were mostly as likely to emphasize the complexity of problems and students' self-image as problem-solvers. The theme was further divided into two subthemes (Table 4).

Table 4
Examples of Encouraging Mistakes for Learning from the Literature

Subtheme	Example Quote
Complex Problems have Complex Solutions (21)	"There isn't always one right answer. You know, there's lots of different ways you can approach a problem and there's lots of different results you can get. In a way that's kind of how the real world goes." (Dare et al., 2014, p. 7)
Promoting Positive Self-Image as Problem-Solvers (20)	"She believed STEM integration helped her students to think independently and to become more confident in learning, to learn how to communicate with each other, and to become skilled at teamwork" (Wang et al., 2011, p. 10)
Avoiding Perfectionism (3)	"James was careful in talking about his students' hesitation to begin work with the wind turbines, almost being afraid to touch the equipment because they were afraid that they would do something wrong" (Dare et al., 2014, p. 10)

4. Promoting Persistence as Productive Struggle: Persistence was also an important skill that teachers identified for success in STEM. Most frequently, teachers and teacher educators referred to persistence in reference to a *mindset* that was open to challenges and the benefits of *productive struggle*, but the literature also reported the importance of setting high expectations for students. Table 5 summarizes the three dominant themes related to persistence; there were a total of 35 utterances related to this theme.

Table 5
Examples of Persistence Themes from the Literature

Subtheme	Example Quote
Mindset (15)	"[Teachers] seemed to hold more growth mindsets, agreeing that hard work and effort could lead to success in mathematics." (Copur-Gencturk et al., 2020, p. 1264)
Communicating High Expectations (10)	"When teachers had high expectations for students, however, these students typically met the higher expectations of performance." (Nathan et al., 2010, p. 410)
Productive Struggle (10)	"Effective schools have been found to embrace and promote a strong common mission and vision, fostered by focused school leaders, that articulates high expectations for minority student success" (Dare et al., 2014, p. 10)

5. Supporting Critical Thinking: In summary, the definition of critical thinking is: Use the scientific method to formulate and solve problems using inquisitiveness and multidisciplinary knowledge. Let them think outside of the box and learn through their own experiences to become self-directed learners. The corpus contained 11 utterances, within two subthemes related to this theme (Table 6).

Table 6
Examples of Critical Thinking Themes from the Literature

Subtheme	Example Quote
Critical Thinking (8)	"[Preservice Teachers Creative and critical thinking, discovery or hands-on learning, problem-based learning (PBL)." (Radloff & Guzey, 2016, p. 766)
Thinking Outside of the Box (3)	"His goal as a teacher is to make a difference in the world through teaching, challenging students to think outside-the-box and not always give them the answer right away" (Dare et al., 2014, p. 7)

Additional Findings: We found 11 articles referencing the importance of building 21st century skills to prepare students for success beyond high school and for future careers. When we analyzed the research, though, we found that most skills or dispositions labeled as *21st century skills* actually overlapped with *STEM Smart Skills* in the five categories above. In other cases, teachers used the phrase *21st century skills* to describe academic competencies rather than life skills and mindsets. Examples include written communication skills and oral presentation skills (Park Rogers et al., 2010). For these reasons, the phrase *21st century skills* does not constitute a separate category of our findings.

Discussion

This systematic review of literature on the research of K-12 educators' beliefs of non-academic skills and dispositions that support students' mathematics and science learning identified six themes. Our literature review identified these five major themes as:

- Encouraging Academic Risk Taking;
- Making STEM Accessible For All and Viewing STEM As Interdisciplinary;
- Embracing Mistakes as Learning Opportunities;
- Promoting Persistence as Productive Struggle; and
- Supporting Critical Thinking.

These *STEM Smart Skills* are separate from explicit content skills and knowledge. Yet the research is clear that teachers' beliefs directly affect their actions and therefore are an important influence on student learning outcomes (Fenstermacher, 1994; Richardson, 1994). Teachers support of *STEM Smart Skills* aligns with Darling-Hammond's (2020) Framework for Whole Child Education which focuses on developing students' wellbeing in academic, cognitive, social-emotional, physical, mental, and self-identity contexts. In particular, *STEM Smart Skills* target self-identity, social-emotional development, and mental health in ways not typically addressed in school.

We are not suggesting that teachers teach *STEM Smart Skills* as part of a curriculum. Rather, we believe our findings demonstrate that the life skills and dispositions of risk taking, integrating disciplines accessibly, making mistakes, promoting persistence, and supporting critical thinking should be infused into teachers' existing interactions with students and their classroom language. By normalizing these *STEM Smart Skills*, teachers strengthen students' abilities to see STEM all around them and to see themselves as being successful in the STEM classroom – and beyond.

Limitations

Although previous research indicates that teacher beliefs are important and connect to classroom practice in meaningful ways, there are a number of limitations and challenges in measuring teachers' beliefs and attitudes. First, there is the limitation involved in all single-instance measurement of attitudes. Further, correlations are not evidence of causation. A teacher's infusion and encouragement of *STEM Smart Skills* in their teaching does not automatically result in student learning. The process of learning is a complicated undertaking, involving a multitude of factors. Simply put, these *STEM Smart Skills*, in teachers' opinions, are necessary but not sufficient for student success in STEM education.

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PANDEMIC PLANNING: EXPLORING MIDDLE SCHOOL MATHEMATICS TEACHERS' CURRICULUM ASSEMBLAGES

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Curriculum has been undergoing a transformation as teachers have greater access to online resources and digital tools (Pepin et al., 2017; Webel et al., 2015). The transformation was further exacerbated by the changes forced by COVID-19 as teachers scrambled to reimagine their curriculum systems in a different context—virtual, hybrid, and concurrent. The four teachers in the study acquired new resources, transformed existing resources, and cut components to fit the changed learning environments created by the pandemic. The goal of the study was to map teachers' curriculum assemblages—collection of curriculum resources—during the COVID-19 pandemic.

Introduction and Relative Literature

COVID-19 has forced significant changes to the learning environment as schools offered classes in different modalities (e.g., virtual, concurrent, and hybrid) to create safe learning spaces and to meet the desires of students and parents (Pace et al., 2020). Additionally, teachers continued to encounter abrupt changes as district policy shifted throughout the pandemic. Teachers introduced new technologies and innovative strategies to meet the demands of the new learning environment caused by COVID-19 (Gouëdard et al., 2020). Furthermore, curriculum has been undergoing a transformation as teachers have greater access to online resources and digital tools (Pepin et al., 2017; Webel et al., 2015). The transformation has been further exacerbated by the changes forced by COVID-19 as teachers scrambled to reimagine their curriculum systems in a different context.

Branching away from the traditional linear sequential notions of curriculum moves the model of curriculum beyond a stable organization to one that is complex, creative, and unstable. Curriculum resources, however, have historically been studied as a set of bounded materials (e.g., textbooks and curriculum programs such as the Connected Mathematics Project, CMP). Teachers' access to seemingly limitless materials online and the changed classroom environment challenges this closed system approach. Teachers are redefining curriculum by accessing resources outside school distributed materials. The diverse range of resources available for teachers demands an increased capacity for them to evaluate and select resources to enact quality instruction (Webel et al., 2015). Furthermore, this transformation of curriculum materials necessitates research approaches aimed at exploring curriculum resources centered around the teachers' compilation of their own collection rather than prebounded sets (e.g., CMP). An open model of curriculum is necessary to reflect how resources are currently being used in middle school, grades 6-8, mathematics classrooms. This post-qualitative inquiry investigated four middle school mathematics teachers' curriculum work during the COVID-19 pandemic guided by the following research question: How do middle school mathematics teachers assemble curriculum during a pandemic?

Theoretical Perspective

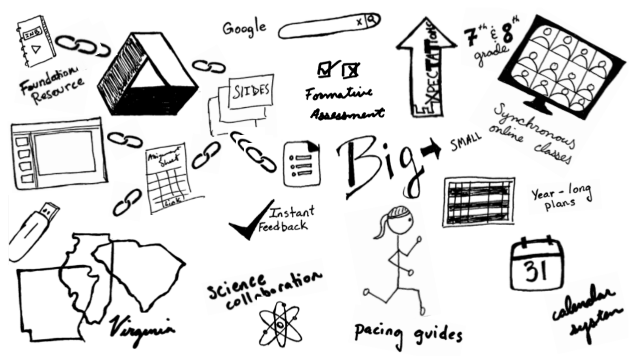
Deleuze and Guattari's (1987) construct of assemblages—a collection of heterogenous components organized to perform some function—was foundational to this study. The theorization of assemblages provided a space for teachers' curriculum work to be considered rhizomatically. Rhizomes are grass-like structures growing in between components creating connections. A rhizomatic structure opens possibilities for bounces between curriculum components and across time (e.g., last year's lesson plans, current plans, and future plans). Moreover, a rhizomatic structure affords opportunities for teachers' curriculum work to be examined non-linearly and created spaces for different connections. An assemblage is not simply a product, but rather the coming into existence or the need to organize, reorganize, and/or construct. As the assemblage shifts or sharpens boundaries map out an assemblage's territory. Conversely, as lines of flight emerge an assemblage blurs or fragments and deterritorializes.

Methodology

I used a methodology of becoming (St. Pierre, 2018) injecting Deleuzoguattarian theory to deterritorialize conventional methodology (Deleuze & Guattari, 1987). I viewed the project as an assemblage of interconnected components: a) lesson plan walkthroughs or interviews discussing teachers' short and long-term planning, b) schematic drawings (i.e., diagrams teachers created depicting their curriculum resource use), c) teacher resources, d) assemblage of terms—a sort of theoretical dictionary produced by the researcher, and e) sketchnotes or drawings combining images and text created by the researcher and used to generate conversations with participants (see Figure 1). Each teacher participated in three, hour long lesson plan walkthroughs, submitted curriculum resources, and created schematic drawings. Data collection and analysis were seen as rhizomatic (Best & Kellner, 1991; Deleuze & Guattari, 1987). The boundaries of data collection and analysis blurred and overlapped throughout the process. Sketchnotes acted as an initial visualization of participants' curriculum assemblages. Then, the researcher created leveled writings (Markham, 2012) opening space for connections by constructing a rhizomatic structure as new concepts and ideas sprouted between previous text integrating quotes from lesson plan walkthroughs, schematic drawings, the assemblage of terms into a composite piece.

Figure 1

Sketchnote of Andrea's curriculum assemblage



Participants

Four middle school mathematics teachers from the southeastern and midwestern United States participated in the study—each selected for the type of environment they were teaching during the 2020 fall semester. Participants were given pseudonyms. Andrea was teaching fully online, Abby taught a hybrid model in which the district made adjustments every 6 weeks to how many days students were learning in-person or online—for the study Abby was teaching four weeks in person and two remotely, Savanna taught in a hybrid environment—students alternated between in-person and remote learning, and Cathy transitioned from seeing students fully online to teaching concurrently (she taught students virtually and in-person simultaneously).

Findings

COVID-19 created changes to the learning environment requiring participants to recontextualize their curriculum assemblage. Savanna articulated planning had changed this year to meet the demands of teaching during COVID-19.

> So, this year yes. Planning does look different. I think that's what we spent a lot of our time before school was just searching other resources. That's how I came across GoFormative because it is something that's just another resource that is good, you know, digital thing.

Participants made choices to preserve, cut, add, substitute, or modify components (e.g., mathematics tasks used in previous years and classroom procedures) within their curriculum assemblages to fit their teaching modality (e.g., hybrid, concurrent, or virtual). Andrea and Cathy faced the biggest shift in their learning environment because they lost all face-to-face instruction with half (Cathy) or all (Andea) of their students and made more drastic modifications to their curriculum assemblages. Their learning environments, past curriculum assemblages, available technology, and planning style influenced these choices. Participants recontextualize their curriculum assemblages by preserving their pre-COVID-19 assemblages, translating components, rearranging activities, and bridging the physical and virtual. At times, however, these approaches were not possible, and components needed to be cut.

Rearranging Activities Based on In-Person versus Virtual Environments

Under the hybrid model, Savanna and Abby's primary strategy for maintaining their curriculum assemblage was to rearrange learning activities. By reorganizing tasks, they believed they could overcome many of the obstacles a virtual learning environment presented. Abby relied on a digital program offering individualized pacing, on remote learning days to introduce topics and provide additional opportunities for students to engage with content covered in the classroom. Abby described how she organized activities in the following quote:

> The last set of remote, it timed itself really well, to where I could give them kind of the benchmark assessment for the end of the 1st quarter…So, I used a [digital program] assessment that are customized, and I can have it provide feedback for them and things like that. Something that I don't necessarily have to facilitate live.

She systematically planned learning activities requiring simultaneous collaboration and discussion to occur when students were in the classroom. Abby was teaching about 65% of the time in-person and relied on rearranging learning activities and existing digital components of her curriculum assemblage to reconceptualize her curriculum assemblage in a hybrid environment.

Savanna also relied heavily on reorganizing lessons according to in-class and remote learning days. Students attended in-person every other day and activities were organized so collaborative and discussion-based activities occurred in the classroom. Savanna determined which activities she wanted to cover remotely and which ones to do in-person, "Is this something I want to work with the students in class, have a conversation with, and this is something they can do on their own." Unlike Abby, Savanna made additional modifications to her curriculum assemblage to meet the demands of the hybrid learning environment. Savanna's students attended remotely more frequently than Abby's which may have contributed to Savanna's additional modifications (e.g., translating, cutting components).

Translating Components from Paper to Digital Formats

Participants translated components of their curriculum assemblages uniquely adapting them to fit the constraints of their context and planning structures during the pandemic. Abby translated components to better facilitate her planning process. Her handwritten planning documents were also translated into Google Slides and Spreadsheets. Abby claimed the transition was to better accommodate the rapid changes in curriculum resources and to plan for the next school year.

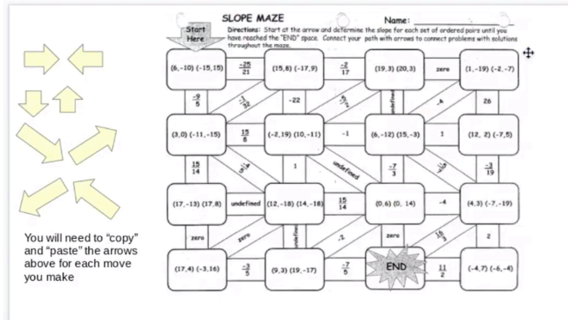
> This time, we've gotten something [Google Spreadsheets] this a little bit more fluid and so I guess dynamic is a better word there where it can shift as expectations and curriculum shifts.

Cathy needed to translate components to accommodate students in the classroom and online. Most activities required a dual delivery. For example, Cathy translated a vocabulary activity into a Quizlet, for virtual students, and a modified for limiting contact "I have, who has" activity for in the classroom. Most of Cathy's translations converted paper tasks into Classkicks—slide shows with the functionality of simultaneous interaction. Cathy converted weekly assessments into Classkicks to provide space for students to demonstrate their mathematical processes.

Savanna translated tasks to fit both virtual and in-person learning environments. She used GoFormative (i.e., a webapp allowing teachers to create interactive assignments) to convert PDFs into multiple choice or short answer questions translating paper pencil tasks into a virtual format. Savanna recognized this presented certain constraints as it did not allow students space to demonstrate their mathematical processes. She also took existing PDFs and converted them into drag and drop tasks in Google Slides providing students space to more actively engage with PDFs (see Figure 2). Her translations did not merely address changes to virtual learning but was also employed to adapt tasks in the physical classroom. Additionally, Savanna converted paper-pencil tasks into digital tasks to reduce contact in the classroom. Goolge Slides were used to allow students to work collaboratively on tasks while remaining physically distanced.

Figure 2

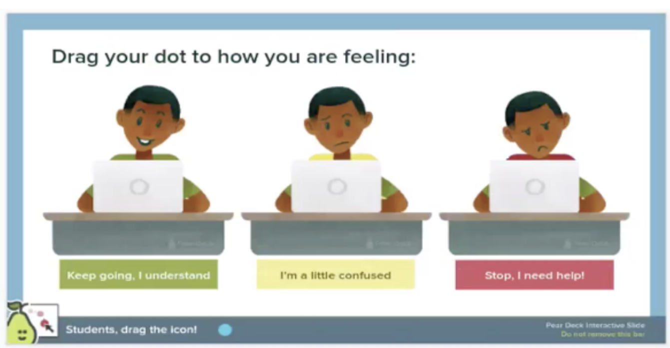
A slope maze PDF converted into a digital drag and drop activity in Google Slides.



Andrea transformed procedures she typically did in a physical classroom and converted them into a digital space. For example, in the past, Andrea used a different colored cup system for students to indicate how well they grasped a specific mathematical concept. Andrea used the informal student feedback to make instructional decisions. Andrea converted this activity by using PearDeck, a Google Slides extensions, allowing students to provide feedback (see Figure 3). Using a translation strategy, Andrea was able to preserve an in-person classroom procedure in a virtual environment. While translations helped Andrea and Cathy reconceptualize their curriculum assemblages, it was not enough to meet the demands of the virtual environment.

Figure 3

Formative student feedback translated into a virtual environment using PearDeck.



Cutting Components

While participants creatively approached preserving components of their curriculum assemblages, some components needed to be cut for the assemblage to function in a new context. I use the term cut to indicate it is not necessarily a permanent removal from the curriculum assemblage but rather like using the cut function in a word document—the extracted components are waiting in a "clipboard" ready to be reinserted. Participants cut components of their curriculum assemblage due to time constraints, student needs, and functionality. Time was particularly a factor for Cathy and Abby because COVID-19 decreased the amount of time students were in their classrooms. They felt forced to alter their curriculum assemblages to accommodate the new schedule and components had to be cut from their curriculum assemblage. Abby was forced to cut exploratory activities she typically used to introduce mathematical topics to make accommodations for lost class time stating, "I have to sacrifice the activities to stay on pace because we do still have an end of course exam." Cathy on the other hand, did not explicitly cut topics or activities from her curriculum assemblage, however, she was weeks behind the district pacing guide and stated she will not be able to cover all the content for the year. Thus, eliminating topics from her assemblage. Savanna and Andrea stated they had not experienced a significant loss of class time due to the pandemic and believed they would cover the same content this year as last year. Time, however, was not the only consideration when participants cut components from their curriculum assemblages.

All four participants demonstrated a willingness to cut components based on students' mathematical needs. They adjusted lessons in the moment to cut tasks students had already mastered to reduce redundancy. Abby and Savanna demonstrated this when they removed examples from their notes after students demonstrated an understanding of the mathematical concept. Savanna's focus on mastery contributed to the components she cut from her curriculum assemblage. She made cuts based on how students performed on previous state tests and how the test was weighted by standard. Participants also cut tasks from assignments or activities containing content not covered in their course. Cathy emphasized she rarely found activities perfectly aligned to her learning targets for the day cutting tasks to better fit her lesson plan.

Components were also removed from their curriculum assemblages when they were no longer functional. Cathy began the year incorporating a variety of online applications to keep students engaged in lessons. Students, however, struggled to move from one application to the next and to remember passwords for each class. Cathy reduced the number of applications she used in her class to create consistency. Structures within the curriculum assemblage were also cut to function differently. For example, Andrea cut slides from her templates to match the content and activities for the day's lesson. Participants were also willing to make large scale cuts to their curriculum assemblage. For example, Abby cut the district textbook for the equations unit because it did not fully address pre-algebra and Algebra I objectives. Cathy made a significant elimination when she removed the district textbook because it was difficult for students to access online and presented mathematical tasks out of context. Cathy cut the district distributed textbook because it was difficult for students to access online and provided mostly low cognitive tasks.

COVID-19 forced participants to reconceptualize their curriculum assemblages to fit a new context—virtual, concurrent, and hybrid modalities. Participants attempted to preserve their pre-COVID-19 curriculum assemblages by translating components, rearranging components, and bridging the physical and virtual world. Participants were able to maintain many components and processes in their curriculum assemblages. Even so, participants faced large shifts in the learning environment, and at times, chose to cut components rather than adapt and modify them.

Discussion

This study examined four middle school mathematics teachers' curriculum work during the COVID-19 pandemic as they scrambled to reimagine their curriculum assemblages in a different context. The participants acquired new resources, transformed existing components, rearranged activities, and cut elements from their curriculum assemblages to fit the changed learning environment. Additionally, participants integrated new technologies (e.g., Classkick and Peardeck) and implemented innovative strategies into their curriculum assemblages echoing the Gouëdard and colleagues' (2020) findings. The COVID-19 pandemic is ongoing and continues to influence the mathematics learning environment. More research is needed to understand how the changes to the mathematics learning environment have deterritorialized mathematics curriculum and how this could influence instruction. Additionally, a potential space of inquiry would be to investigate how teachers recontextualize their curriculum assemblages as they transition back to in-person classes and restrictions from the pandemic ease. What digital tools, new resources, and procedures will remain teachers' curriculum assemblages? A space of becoming could emerge as the tension between pre-COVID-19 and COVID -19 curriculum assemblages push and pull on each other.

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THE IMPACT OF STATE PROMOTION POLICIES ON TEACHER PRACTICE AND DECISION MAKING: A CASE STUDY OF NEW YORK CITY MIDDLE SCHOOL MATHEMATICS TEACHERS

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The present multiple case study explored three New York City mathematics teachers' experiences and perspectives with social promotion and academic promotion criteria. This study described and highlighted how the NYC promotion criteria policies impact their teaching and decision-making. The result indicated that (i) promotion policies do not directly impact teacher decision-making and teaching practice; (ii) school administrators impact teacher's decision-making the most; (iii) social promotion significantly impacts students in mathematics because of the vertical progression of math skills and concepts; (iv) some students arrive at middle school with gaps in their math skills.

Overview of the Literature and Conceptual Framework

In order to answer the central question of this study, the impact of promotion policies on teacher decision making and teaching practice, the researcher explored literature around teacher decision making, and the impact promotion policies have on middle school math students. First, it is essential to understand the factors that influence teacher decisions because teacher decision-making is the center of the research. Decision-making is crucial to a teacher's career. During instruction, the teacher has to focus on various things including, the concept, the strategy, assessment of students' understanding, and students' behavior.

The complexity of the decision-making process is not solely due to the decision itself but also because of the different factors influencing these decisions. As teachers make decisions daily within their classrooms, there are also factors outside of the classroom that impact this process. Shavelson and Stern (1981) explain six factors that also influence teacher decision-making. These factors are: information about students, instruction task, classroom, school environment, teacher characteristics, and teachers' cognitive process. Some of these factors are a part of the conceptual framework of this study.

Second, an understanding of the impact promotion policies have on math education is important to this study. Mathematics is a subject that involves a vertical progression of skills and concepts. As students advance to higher grades, the skills and concepts they developed are from their previous conceptual knowledge. "Conceptual knowledge is described as the relationships and interconnections of ideas that explain and give meaning to mathematical procedures" (Lin et al., 2013, p. 2). The lessons students learn are all connected to other concepts.

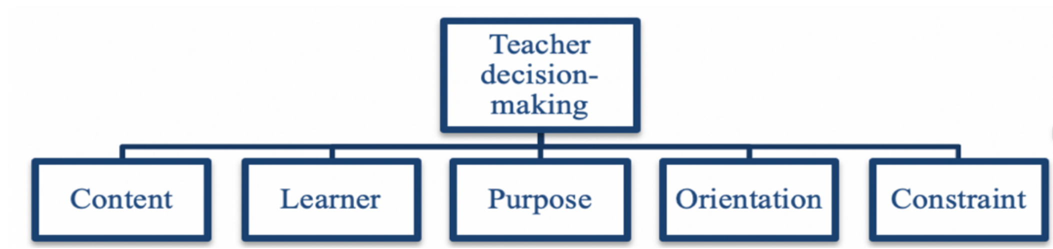
Therefore, socially promoting students creates a problem in math because students lack the foundational skills to be successful. Students should learn within their zone of proximal development. The zone of proximal development is the skill level in which students can develop mastery with assistance (Poehner, 2012). Although social promotion can impact students' math learning experiences, there is limited research on the effect of promotion policies on middle school students' mathematics achievement.

The Conceptual Decision-making Framework

The researcher developed a conceptual decision-making framework (see Figure 1) from the synthesis of literature around teacher decision-making. Decision-making is essential to the teaching profession. For example, a teacher has to decide on lesson designs and on-the-spot decisions or judgments in the middle of the classroom in session (Guerriero & Deligiannidi, 2017). The decision-making framework focused on five major elements.

Figure 1

Teacher Decision-making framework



The first element of this framework explored how promotion policies impact teachers' decisions related to their content knowledge and pedagogical knowledge, including but not limited to, curriculum and planning. Teachers must also acquire the necessary skills to effectively apply their knowledge to ensure that all students learn (Burden & Byrd, 2015). As teachers plan their lessons in a diverse classroom setting, they must apply the necessary skills.

Second, teachers' orientation consists of their beliefs, theories, and attitudes. In a study on the influence of attitudes and behavior, Ajzen and Fisbein (2014) explains two types of attitudes. The first attitude is the general attitude someone has towards an object, and the second refers to attitudes toward a behavior (Ajzen & Fisbein, 2014). Gaining insight into teachers' orientation helped the researcher understand the impact of promotion policies on teachers' decision-making at a deeper level.

Third, the learner: students' backgrounds and knowledge are central to teacher instructional decision-making. It is important that teachers know their students' strengths and weaknesses to create differentiated lessons to meet different preferred learning styles. It is also essential that students are engaged in the learning process (McMillan & Nash, 2000).

The fourth element critical to the framework is the teachers' purpose and philosophy. Purpose involves the philosophy, attitude, and style that the teacher brings to teaching. One of the most significant internal factors influencing teacher decision-making is their teaching and learning philosophy (McMillan & Nash, 2000). Therefore, it is essential to understand how teachers' philosophy impact their decision. Investigating the role that philosophy played or did not play helped the researcher to understand the participants' positions on promotion policies.

The final element in this framework is teachers' constraints. A complete insight into teacher decision-making is impossible without knowing the constraints that impact teachers. Teachers' actions experience obstacles through physical and external settings (Prenger & Schildkamp, 2018). This decision-making framework informed this study's research questions and data collection and analysis procedures.

As a result of the lack of research on this topic, the researcher decided to conduct a multiple case study to investigate the impact of promotion policies on middle school math teachers' decision-making and teaching practice. The central question for this study was: How do academic and social promotion criteria policies influence teacher decision-making and practice? A conceptual framework for teachers' decision-making was utilized to guide this research.

Overview of Data Collection and Analysis Procedures

The researcher used purposive sampling to select three middle school math teachers in New York City in this study. In the initial stage of the data collection process, a questionnaire was sent to approximately thirty middle school teachers in NYC. Nine teachers responded, and three of the respondents were selected based on their responses to the questionnaire. These three respondents became the participants of this study. They participated in interviews based on their fitting one or both of the following criteria: teachers who had changed students' grades to meet promotion criteria and teachers who taught socially promoted students.

The interviews were conducted through Zoom, transcripts transcribed and saved using participants' initials. Data analysis was centered around Creswell's (2018) data analysis spiral to analyze each case. The data was initially read thoroughly five times, and the researcher took notes and highlighted significant and common ideas. After the initial reads, the researcher created charts with codes and common themes developed from the data for each participant. The researcher then used the elements from the conceptual framework as a road map to analyze the individual cases.

After the individual case analysis, a cross-case analysis was used to identify common patterns across all the cases. The researcher identified four major themes that emerged across the cases. First, each teacher discussed different factors impacting their decisions, including curriculum, students, pacing calendar, and time. The second theme centered around teacher decision-making. After carefully analyzing and reviewing each case, the researcher noticed that each teacher had some experiences that demonstrated the lack of teacher decision-making at their school. The third theme was teachers' reaction to and perceptions of social promotion and retention. All participants had experiences teaching students who experienced social promotion and retention. The teachers believe that students become frustrated and unmotivated when they experience social promotion. The impact of the promotion policies was the fourth major theme of this study. During this cross-case analysis, the researcher analyzed the similarities between the participants' experiences. The following sections describe the key findings and recommendations of the study.

Summary of Key Findings

The cross-case analysis of the individual cases yielded three findings. This study revealed that promotion policies impacted each teacher differently. Although each teacher had their own experience with these policies, there were three major commonalities in the findings.

Finding One

The first finding answers the research question, revealing that promotion policies do not directly impact teacher decision-making and teaching practice. Results showed that administrators, curriculum, pacing calendar, time, students' needs, and the learning gap influence teachers' teaching practice. According to the participants, the school administrators make the decisions based on policies that are in place and then provide instructions to the teachers.

Although promotion policies are in place, the findings revealed that not all school administrators follow them. One of the participants shared that some of the decisions that are made are not all aligned to the city's promotion guidelines, stating,

> I find it unfair or inequitable to identify more than ten students who do not meet promotional criteria and then narrow it down to only ten based on additional school made criteria feels unfair because why do student x but not student y pass the grade other than teacher preference since the criteria are not applied evenly.

Some teachers are also asked to use informal procedures, such as their perspective on students' behavior when selecting students for promotion. Another shared that some instructions from administrators resulted in going against personal beliefs.

Finding Two

The results showed that teachers believe that social promotion significantly impacts students in mathematics because of the vertical progression of math skills and concepts. In mathematics, students rely on previously taught skills and concepts to understand or gain a deeper understanding of new ideas at their current grade level. Therefore, when students do not have these prerequisite skills, they struggle to understand and master new materials. As a result of some of these academic struggles, students become frustrated and unmotivated to learn. Additionally, results revealed that when some students are socially promoted, they are not provided with additional academic support, so they continue to struggle.

Finding Three

The results also showed that the participants believe that students' math incompetency is rooted in elementary school. Teachers from this study reported that students' learning gaps in math begin in elementary school. One participant shared, "a majority of students are entering middle school far below grade level." Another participant expressed, "if students are missing foundational blocks in the lower grades, then it has a detrimental impact on their performance in the later grades."

Recommendations

As a result of this current study's findings, based on the perspectives of the three participants, necessary changes and more research are needed regarding school policies, practices, and settings as it relates to struggling students in math. First, school districts should employ strategic systems to ensure school administrators follow promotion policies. Second, all schools need to provide additional support to their struggling math students consistently. If a student is socially promoted or repeating a grade, additional academic support should be provided to the student. It is important that students are learning grade-level skills in math so they will not struggle as they progress in grades. Third, teachers should be more involved in the decision-making process involving students. Finally, there needs to be more research to investigate the root causes of math deficiency in middle school students and the impact social promotion has on these students.

Conclusion

The findings revealed that administrators decided to promote students to the next grade in some schools in NYC even when they did not meet the promotion criteria. Also, this study showed that schools do not always provide additional support to students who struggle. Furthermore, although teacher decision-making is an important aspect of the profession, teachers do not receive opportunities to make certain decisions. They are sometimes placed in a compromising situation when asked to do something contrary to their beliefs. In addition, students are arriving at middle school with gaps in their math foundation.

In conclusion, although this study revealed several interesting findings regarding teacher decision-making, more research is needed, including a study with a larger sample size. Additionally, more studies on the impact that social promotion has on students' math learning experiences are also needed.

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Moving Forward, Leaning in: Acceleration over Remediation For Pre-Service Teachers

STUDENT VOICES AND REFLECTIONS ON THEIR MATHEMATICS TEACHER PREPARATION PROGRAMS

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Continuous improvement of teacher preparation programs is influenced by various sources (e.g., state policies, university culture, program environment, faculty, needs of local schools). An often overlooked perspective on teacher preparation programs is students' voices. Here we discuss mathematics teachers' beliefs about the strengths and weakness of their preparation program. Findings indicated that students experienced differences between what they expected to get out of certain courses and what we, as faculty, expected them to learn. Although these are not novel issues, they are pertinent issues related to improvement of teacher education and serve as the impetus for conversations around programmatic improvement.

Pre-service secondary mathematics teachers take a variety of mathematics, education, and/or mathematics education courses in their programs (Darling-Hammond et al., 2005). The courses and structure of the program are heavily tied to the institutional context. Local institutional contexts are always looking to improve their programs to enhance the recruitment and retention of students, as well as improve the overall teacher education experience. Student voices and perspectives are an important, yet often overlooked, component in the process of instructional changes related to improving these programs (Allen & Peach, 2007; Fielding, 2001). In this work, we share findings from student voices and perspectives on their beliefs about how their program is preparing them or has prepared them to be teachers. Our research question was: *What do preservice and inservice teachers believe about how their program is preparing them to be teachers or has prepared them to be teachers?*

Literature

In the broader teacher education field, there is much literature on teacher preparation programs, oftentimes using student achievement to discuss successful programs (e.g., Boyd et al., 2009; Koedel et al., 2015). More recently, though, focus has shifted to standards for mathematics teacher preparation that are not solely about student achievement. In 2017, the Association of Mathematics Teacher Educators (AMTE) published the *Standards for Preparing Teachers of Mathematics*. To assess candidates, AMTE recommends assessing mathematical knowledge relevant to teaching, mathematics teaching practice, and dispositions. Regarding programs, AMTE recommends assessment of stakeholder engagement, program curriculum and instruction, effective clinical experiences, and recruitment and retention. Thus, given these important standards and recommendations, the teacher education field needs to know how these standards are communicated to students in teacher preparation programs. Having teachers reflect on their instructional practice is a well-documented successful strategy for teacher education (e.g., Etscheidt et al., 2012); we aim to use reflection in this work at the programmatic level.

Methods

Research Design and Context

Our research question was: *What do preservice and what did inservice teachers experience in their mathematics teacher preparation program?* To answer this question, we conducted an exploratory convergent parallel design study (Creswell & Creswell, 2017; Tashakkori & Teddlie, 1998), wherein we designed a survey to collect both qualitative and quantitative data, and results from both data sets are used to compare or relate our findings for an overall interpretation.

A survey was sent to our current undergraduate middle-grades and/or secondary mathematics education students and former graduates from these programs from the last 10 years. The university is in the southeastern United States and is a UTeach replication site. Students can either major in Mathematics (with an emphasis in Secondary Education) or Middle Grades Mathematics. Both degrees also require an additional major in Science and Mathematics Education. In some cases, students get all three degrees. The Mathematics and Middle Grades Mathematics courses are taught by mathematics education or mathematics faculty within the Mathematics Department. The Science and Mathematics Education courses are taught by education faculty in the School of Education. The faculty in both units work together, when possible, to provide a cohesive experience for students. However, there is not a formal connection between content and education courses. In the mathematics courses the focus is strictly on content whereas the education classes focus on the various aspects of teaching.

Data Collection

To solicit responses, we used alumni email lists and current student departmental email lists. In all, 69 participants filled out the survey (15 current students and 54 former students). The survey collected demographic information, open-ended responses, and Likert-scale questions. The demographic information was gender identification, race, ethnicity, first-generation college student status, majors, minors, and classification (former student, senior, junior, sophomore, first-year). The quantitative data were Likert-scale questions (strongly agree to strongly disagree) where participants were asked how their program was preparing or has prepared them to: 1) teach mathematics in a student-centered way; 2) inquire into my students' mathematical thinking; 3) assess students' mathematical knowledge; 4) prepare mathematics lessons; 5) solve mathematical problems; 6) support diverse students and diverse student thinking; and 7) make connections between mathematics content. Example open-ended questions for former students were: 1) Please describe your teaching style and why that is your approach to teaching mathematics; 2) What about our program, in regard to your [mathematics / education] courses, [did / did not] prepare you for your current position? Current students were asked similar questions, rephrased to be applicable to them.

Data Analysis

To analyze the quantitative data, we hoped to perform an ordinal logistic regression of the five-point scaled Likert items – comparing students' majors and their classifications. Unfortunately, the data did not meet the assumptions for this regression approach, particularly we failed the proportional odds assumption ($p < 0.001$). Additionally, in looking at the raw scores for students, many students responded similarly to one another with little deviation (i.e., most students responded with somewhat or strongly agree on all Likert items) – indicating that there was little to no difference in how students responded based on major or classification. As such, we will focus predominately on the qualitative data analysis for this project.

To analyze the qualitative data, we did open coding and thematic analysis (Braun & Clarke, 2006). As the crucial component of our study was to lift students' voices and reflections about their teacher preparation programs, we did our initial coding in vivo. Two researchers individually coded all the data. They then discussed disagreements on coding to continue to refine the codebook. Then all three researchers coded the data with the refined codebook. All three met to discuss changes that needed to occur to have an agreed upon codebook.

Results

Recall our research question was: *What do preservice and inservice teachers believe about how their program is preparing them to be teachers or has prepared them to be teachers?* We conducted an exploratory convergent parallel design study to answer this question. We found three overarching themes of students' experiences in our programs. The three themes are 1) connections to content they will teach, 2) what is good pedagogy, and 3) classroom management.

Connections to Content They Will Teach

In responses to various questions, former students commented on how their mathematics courses tied directly to what and how they are now teaching their students. Specifically, there were 15 comments from former students that mentioned seeing this connection. Several comments focused on direct content connections. For example,

> My courses gave me a good background to the knowledge I already had, which allows me to more easily break down the content for students. The best example I have is the geometry course I took. We delved further into geometry proofs than normal high school curriculum goes, but that knowledge has helped me create a foundation of learning for my sophomore geometry students.

Likewise, another former student said,

> I felt like the courses I took at University X were very helpful in preparing me for teaching mathematics. I learned a lot about how connected the various parts of mathematics were which helps me to use those connections with my students currently.

Additionally, several former students discussed not only the connection between what they learned but how the classes were taught. "[I] developed a better understanding of the 'why' behind the mathematics, an understanding of how secondary concepts are used in post-secondary mathematics, and learned concepts that I now teach that I did not learn in school." And some students referenced certain classes.

> The problem solving class was THE most effective class for teaching me how to teach math, and it wasn't even a teaching class directly. It made me realize how students struggle and what makes a difficult problem fun, and I strive to recreate or use problems from that class in my own classroom. I also really think the class with [professor] helped with explicitly integrating math practices and finding research based (even multi-disciplinary) inquiry activities to do with students.

From these comments we are encouraged that these students are taking their experiences in college level mathematics classes and connecting them to their practice as teachers. However, not all participants mentioned similar experiences. Some former, as well as current students, commented on not seeing the connection between their mathematics courses and what they teach or will be teaching (i.e., Horizon Content Knowledge (Ball et al., 2008)). Specifically, there were 12 related comments. These comments often centered on the idea that the content that was taught in their undergraduate mathematics classes was beyond the content that they teach their middle or high school students. For example, one respondent said “There was not a lot of information targeted at helping us teach mathematics to students. For example, what are common misconceptions high school students have about math and how can we counteract that in the classroom.” Another said, “the higher level classes are just not that applicable.”

Additionally, several comments stated that the undergraduate mathematics classes should have discussed the aforementioned middle and high school content. “I would have appreciated more of an in-depth look at the content I’m currently teaching my students. While we covered some parts of the content, there was much that I am now teaching that I didn’t see … in college.”

Perhaps, the comment that summarizes these student experiences best addresses both mathematics and education classes simultaneously.

> Creation of content is one area that I wish I would have been given more of a chance to practice. [Education classes] taught me to teach lessons, and the mathematics [classes] taught me to understand the math. However, I did not have a chance to really marry the two skills. It would have been helpful to have a course solely dedicated to creating content … that checked for higher-order thinking questions and rigorous task creation.

A take-away from this finding is that students currently in our program and those who have completed it, vary in terms of what they expected certain courses to give them. The mathematics courses in our program are designed to be college-level mathematics classes that are taught in student-centered ways focusing on conceptual understanding, and then that conceptual understanding connects to the content they will teach. As this was not consistent across participants, this indicates potential programmatic clarity issues (e.g., transparently explaining to our students the purpose of the program design and specific classes).

What is Good Pedagogy?

Another theme that emerged from our data was confronting the idea of what good pedagogy is and where students see it. Preservice teachers experience pedagogy, from a learner’s point of view, in their own classes or in their field experiences. Twelve participants discussed, from their point of view, how their mathematics classes were taught. For instance, one participant said, “Many of the mathematics courses within the Middle Grades mathematics degree were designed as inquiry based courses themselves. As such, they served as a good model of how to teach math using this method.” While another said,

> All of the Middle Grades mathematics courses I had challenged me to think about the 'why' for each math skill and operation, not just the how. This deeper understanding helps me identify student misconceptions.

There were a few instances of former students saying that courses they took were not student centered, but they often referenced specific courses (e.g., Abstract Algebra) which Secondary Mathematics majors take and those courses are not taught by mathematics education faculty within the department. Importantly, when participants referenced good pedagogy, it often focused on student-centered instruction. Interestingly though, when we asked former students to describe their teaching style, 16 were coded as all or leaning student-centered, 15 were coded as all or leaning teacher-centered, and 14 were coded as a mix between the two. This is an almost even split. Further, some participants who identified as leaning teacher-centered were also the same participants that mentioned the disconnects in the previous theme.

Regarding education classes, the comments on what is good pedagogy often focused on how those classes focused on inquiry-based learning but especially focused on experiences in the field. There were 18 comments from current and former students addressing the importance of field experiences. For instance, one participant said, "I believe getting to actually teach students early…, gave me confidence in classroom management. While teaching real students, I began creating my teacher personality."

Classroom Management

Overwhelmingly, 23 participants expressed a wish for more learning in their program on classroom management. One participant said, "I felt unprepared to deal with a class of 30 students when the time came." Whereas, another participant mentioned classroom management but acknowledged the importance of being in the K-12 classroom to learn about that. "I am not sure if there is a way to prepare for classroom management without having your own classroom, but that is the one skill I wish I could have gotten more experience in."

Discussion and Conclusion

We sought to understand what students experience when they go through a mathematics teacher preparation program. Our findings are heavily tied to our institutional context as a UTeach replication site and how we have several mathematics education faculty housed in the mathematics department. Thus, our findings not only inform practically how we can improve our program, but they illuminate overarching gaps between how we design our programs and what students experience when they go through them (or what they expect to get out of a program).

From our data we found three overarching themes about students' experiences in teacher preparation programs. First, there was a split between participants in terms of ones that experienced the connections to content they will teach when in their undergraduate mathematics classes to ones who did not see that connection. Second, what is good pedagogy was discussed in the context of both how we as mathematics education faculty teach our courses and their experiences in the field. Third, classroom management was something that a large majority of participants wished was a focus of their learning.

Together, these three themes highlight an important take-away for the field of mathematics teacher education. That is, what is the purpose of a program in mathematics teacher education (and the courses within it)? Often in academia, program design is shrouded behind administrative procedures that students never need to know about (Fielding, 2001). They are at a university to get a degree. Those degrees vary by state and university. However, our findings indicate that if we want students to get the best possible experience out of their teacher education program (as they often are designed based on research or community standards (e.g., AMTE, 2017)), then an important component of that is to include students in program-level discussions and be transparent about what they should get out of an education. We acknowledge that our findings are very specific to our institutional context, however, according to Chan (2016), "student expectations and purposes for completing undergraduate education tend to be instrumental and personal, while institutional aims and purposes of undergraduate education tend to be highly ideal (i.e., life- and society-changing consequences)" (p. 19). We believe this is a larger concern in teacher preparation.

This work provides initial steps in building program reform that is rooted in students' voices and experiences of their program. Moreover, implications from this work will inform the teacher preparation research community about perspectives on their education which can be used to understanding, from a student point of view, if programs are achieving their goals. Further research is needed to ascertain if these disconnects have long lasting effects on effective teaching or on the retention of teachers in the field.

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EXPLORING THE CAPACITY OF REMOTE COMMUNICATION TECHNOLOGIES TO ALLEVIATE MATH ANXIETY IN UNDERGRADUATE MATH COURSES

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In this study, undergraduate students at the University of Arizona reflected on remote mathematics classes and took the Abbreviated Math Anxiety Scale; 891 participated in 2020, and 308 in 2021. We reported previously that 36% of students experienced a decrease or no change in math anxiety during Spring 2020 remote instruction. In this follow-up report, we find that 31% reported a decrease in math anxiety after a year of remote learning and explore the capacity of remote communication technologies to alleviate math anxiety. We emphasize the importance of student-instructor communication and suggest remote tools to bring into the in-person classroom.

Introduction

In Summer 2020, we initiated a study at the University of Arizona to understand the impact of emergency remote learning on undergraduate students' math anxiety. We considered a wide variety of factors including a student's demographic information, remote classroom experiences, and personal situation during the COVID-19 pandemic. For our participants, the factors most likely to impact their math anxiety during the emergency transition to remote learning were *access to quality technology* as well as *availability of, and comfort with, communication with their instructor* (Lanius, Frugé Jones, Kao, Lazarus, & Farrell, 2022). In Summer 2021, we conducted a follow-up survey to understand the impact of continued remote instruction on undergraduate students' math anxiety, and to answer the following research question: *What role did instructor-student communication mediated through technology play in the development or mitigation of math anxiety in Spring 2020 and Spring 2021 remote learning?*

Background

Math anxiety is characterized as negative emotions that disrupt one's ability to work with numbers or to solve math problems (Richardson & Suinn, 1972). This anxiety emerges both in academic situations - for example when a teacher asks a student to solve a math problem - and in everyday life. Generally, high math anxiety is inversely correlated with academic achievement (Foley, Herts, Borgonovi, Guerriero, Levine, & Beilock, 2017).

While there is a wide range of causes of math anxiety, we will focus on the capacity of instruction style and classroom experience to provoke or relieve math anxiety. For example, Jackson and Leffingwell (1999) found that an insensitive or uncaring attitude from a teacher can contribute to math anxiety, and Bekdemir (2010) found that instructor interactions that make students feel uncomfortable and insecure negatively affect math anxiety levels. Turner, Midgley, Meyer, Gheen, Anderman, Kang, & Patrick (2002) showed that a high demand for correctness in the classroom combined with limited feedback causes students to avoid mathematics, and Lin, Durbin, & Rancer (2017) showed that an argumentative or aggressive communication style can increase students' math anxiety levels. On the other hand, instructors can help their students to lower math anxiety by guarding against negative classroom environments (Suárez-Pellicioni Núñez-Peña, & Colomé, 2016).

Framing

Suárez-Pellicioni, et al. (2016) argue that the goal of studying math anxiety should be to provide intervention, to both prevent its development and to reduce its negative consequences for those already experiencing high math anxiety. Mynatt & Phelps-Gregory (2021) further suggest researchers recognize the different ways individuals develop and experience math anxiety, rather than looking at math anxiety as a single phenomenon. Accordingly, our research aim will be intervention with a lens that recognizes the individualized nature of math anxiety.

Methods

Our research instrument was a survey hosted through Qualtrics. With approval from the University of Arizona's Human Subjects Protection Program (IRB), we emailed an invitation to all students who took a Spring 2021 undergraduate-level math course. To preserve anonymity, we did not track the number of participants who participated in our prior survey (Lanius, et al., 2022) and 2021. No participants in either year received compensation for their time.

To measure math anxiety, we employed Hopko, Mahadevan, Bare, & Hunt's (2003) Abbreviated Math Anxiety Scale (AMAS). To complete the AMAS, participants are instructed to picture their level of anxiety in 9 situations and to rank their level of anxiety using a 5-point Likert scale, where 1 means low or no anxiety and 5 means high anxiety. We modified wording slightly from the original AMAS to use terms students at our university would be more familiar with (Lanius et al., 2022). A total anxiety score ranging from 9 to 45 is obtained by summing the participant's answers to the 9 items.

In summer 2021, we asked participants to complete the AMAS at first while picturing their level of anxiety shortly after the Spring 2020 transition to remote learning. We then instructed them to complete the AMAS a second time while reflecting on their Spring 2021 remote course. This gives us two sets of reflection data. We will refer to these as reflection AMAS scores. Our surveys contained some novel items focused on the structure and experience of participating in a remote mathematics course. Our surveys concluded with free response prompts allowing students to share what they felt supported or hindered their learning in their remote course. Quotations from these written reflections will appear in our discussion.

Demographics & Data Cleaning

For information concerning the demographics of participants and data cleaning in our 2020 data set, see Lanius et al., 2022. Among the 7,207 students invited to participate in 2021, 308 volunteered to participate. Because we needed to compute an AMAS score for each participant, we only used the data from students who completed all 9 items in the AMAS twice. Thus, after cleaning, we had 216 participants in 2021; 116 were female, 94 were male, and 6 were non-binary/agender or did not report gender. Participants took a wide range of math courses, with 91 in a 100-level, 51 in a 200-level, 43 in a 300-level, and 21 in a 400-level. The average anxiety score of 2021 participants reflecting on the emergency remote semester was M = 27.50 (SD = 9.603) and the average score reflecting on Spring 2021 was M = 27.58 (SD = 9.046). Note that Maloney, Waechter, Risko, & Fugelsang (2012) explain that an AMAS score from 9 to 19 points indicates low math anxiety, while a score ranging from 31 to 45 points indicates high math anxiety. A comparison of our 2020 and 2021 average math anxiety scores can be found in Table 1.

Table 1

Average AMAS reflection scores

	reflect on Spring 2020 courses pre-COVID	*reflect on Spring 2020 courses post-COVID*	*reflect on Spring 2021 remote courses*
Summer 2020 participants (Lanius et al., 2022)	**M = 22.02** (SD = 6.89), N = 834	**M = 26.71** (SD = 8.619), N = 834	
Summer 2021 participants		**M = 27.50** (SD = 9.603), N = 216	**M = 27.58** (SD = 9.046), N = 216

Testing for Normality

A series of Shapiro-Wilk tests showed a significant departure from normality for our Summer 2021 average anxiety score data: $W(216) = 0.98$, $p < .001$ for reflecting on Spring 2020 and $W(216) = 0.98$, $p = .006$ for reflecting on Spring 2021. Accordingly, we used the nonparametric (Wilcoxon, Mann-Whitney, & Kruskal-Wallis) statistical tests in our analysis. We completed our analysis using SPSS version 27 (2020).

Results

Among summer 2021 participants, the average change in anxiety score between reflecting on the emergency remote and the planned remote semester was M = 0.08 (SD = 6.968); however, a Wilcoxon signed-rank test showed this average change was not statistically significant (Z = -0.293, p = 0.769).

Table 2

Changes in reflection math anxiety score

	reflect on Spring 2020 courses pre-COVID	*reflect on Spring 2020 courses post-COVID*	*reflect on Spring 2021 remote courses*
Summer 2020 participants (Lanius et al., 2022)	**64.4%** experienced an **increase** in score **15.5%** experienced **no change** in score **20.1%** experienced a **decrease** in score		
Summer 2021 participants		**25.5%** experienced an **increase** in score **43.5%** experienced **no change** in score **31%** experienced a **decrease** in score	

Between reflecting on the emergency remote semester and reflecting on the Spring 2021 planned remote semester, 94 students experienced no change in math anxiety score and 67 students had a decrease. For most students this decrease in AMAS score was quite moderate, with 40 students having a decrease of 1 to 3 points. We had 55 students with an increase in math anxiety score between reflecting on the emergency remote semester and reflecting on the planned remote semester. For 24 of these students, the increase was again mild and ranged from 1 to 3 points. A comparison of these 2021 ratios of AMAS score increases and decreases compared to the 2020 participant pool can be found in Table 2.

Student-Instructor Communication

In Spring 2020 and Spring 2021, the officially sanctioned remote teaching platform for the University of Arizona Department of Mathematics was the video-conferencing program Zoom. This platform allowed for students to type questions and responses into a chat window during live class sessions (unless the instructor disabled this feature). For asynchronous communication, 61 students reported that they used a discussion forum embedded in the university's learning management system. External communication options reported by students included the question-and-answer forum Piazza (24 participants), the instant messaging platform Discord (41 participants), business communication platforms Microsoft Teams (53 participants) or Slack (1 participant), and mobile group messaging app GroupMe (53 participants). Note that some students reported using more than one of these.

For capturing students' impressions of communication with their instructor we used the statements "I was comfortable discussing classroom questions and concerns with the instructor" (response rates in Table 3), "The instructor was available to address questions and concerns during class and/or outside of class" (response rates in Table 4), "The feedback on assignments was clear and helpful" (response rates in Table 5), and "The instructor clearly communicated the course expectations" (response rates in Table 6).

Table 3

"I was comfortable discussing classroom questions and concerns with the instructor."

		reflect on Spring 2020 courses post-COVID	*reflect on Spring 2021 remote courses*
Summer 2021 participants		Kruskal-Wallis H(2)=46.624, (p < .001)	Kruskal-Wallis H(2)=40.808, (p < .001)
	Agree	**M = 23.87** (SD = 7.785), N = 83	**M = 24.01** (SD = 7.405) N = 94
	Neutral	**M = 25.87** (SD = 9.462), N = 52	**M = 25.06** (SD = 8.934), N = 35
	Disagree	**M = 33.33** (SD = 8.938), N = 72	**M = 32.57** (SD = 8.544), N = 79

Table 4

"Instructor was available to address questions/concerns during class and/or outside of class."

		reflect on Spring 2020 courses post-COVID	*reflect on Spring 2021 remote courses*
Summer 2021 participants		Kruskal-Wallis H(2)=15.645, (p < .001)	Kruskal-Wallis H(2)=30.066, (p < .001)
	Agree	**M =25.46** (SD = 8.630), N = 112	**M = 24.63** (SD = 7.587) N = 120
	Neutral	**M = 28.78** (SD = 9.569), N = 54	**M = 29.13** (SD = 9.261) N = 46
	Disagree	**M = 32.22** (SD = 10.369), N = 41	**M = 33.68** (SD = 9.337), N = 41

Table 5

"The feedback on assignments was clear and helpful."

		reflect on Spring 2020 courses post-COVID	*reflect on Spring 2021 remote courses*
Summer 2021 participants		Kruskal-Wallis H(2)=36.841, (p < .001)	Kruskal-Wallis H(2)=38.442, (p < .001)
	Agree	**M = 23.18** (SD = 7.477), N = 65	**M = 23.46** (SD = 6.924), N = 71
	Neutral	**M = 26.50** (SD = 9.157), N = 72	**M = 25.69** (SD = 8.662), N = 62
	Disagree	**M = 33.01** (SD = 9.285), N = 70	**M = 32.59** (SD = 8.763), N = 74

Kruskal-Wallis tests showed that with statistical significance, on average, summer 2021 participants who felt uncomfortable discussing concerns with their instructor (Spring 2020 reflection H(2) = 46.624, p < .001, spring 2021 reflection H(2) = 40.808, p < .001), who felt that their instructor was unavailable (Spring 2020 reflection H(2) = 15.645, p < .001, spring 2021 reflection H(2) = 30.066, p < .001), who felt they had inadequate feedback on assignments (Spring 2020 reflection H(2) = 36.841, p < .001, spring 2021 reflection H(2) = 38.442, p < .001), or who felt the instructor did not clearly communicate expectations (Spring 2020 reflection H(2) = 22.854, p < .001, spring 2021 reflection H(2) = 27.026, p < .001) experienced a high level of math anxiety (meaning an AMAS score greater or equal to 31). On the other hand, students who felt satisfied by their communication with the instructor on average experienced moderate math anxiety. (Note 2020 participants on average reported moderate math anxiety prior to the COVID-19 pandemic). Instances of a high math anxiety average are highlighted in Tables 3 – 6.

A Kruskal-Wallis test showed a statistically significant difference in a student's reflected math anxiety score based on a change in comfort with communicating with their instructors between spring 2020 and spring 2021 (H(4) = 29.568, p < .001). The students who were uncomfortable communicating in Spring 2020 who became comfortable in Spring 2021 on average experienced a *decrease* in reflected AMAS score of 11.40 points (See Table 7).

Table 6

"The instructor clearly communicated the course expectations."

		reflect on Spring 2020 courses post-COVID	*reflect on Spring 2021 remote courses*
		Kruskal-Wallis H(2)=22.854, (p < .001)	Kruskal-Wallis H(2)=27.026, (p < .001)
Summer 2021 participants	*Agree*	**M = 24.65** (SD = 8.471), N = 95	**M = 24.53** (SD = 8.107), N = 111
	Neutral	**M = 28.60** (SD = 10.246), N = 60	**M = 28.98** (SD = 7.966), N = 47
	Disagree	**M = 32.42** (SD = 8.813), N = 50	**M = 32.51** (SD = 9.605), N = 49

Table 7

Change in Reflection Math Anxiety by Differences in Comfort Communicating with Instructor

	Change from Spring 2020 to Spring 2021 instructor	Average change in math anxiety from Spring 2020 to Spring 2021
		Kruskal-Wallis H(4)=29.568, (p < .001)
Summer 2021 participants	Big *decrease* in communication comfort	average increase **M = 2.59** (SD=11.181), (N=17)
	Slight *decrease* in communication comfort	average increase **M = 1.40** (SD=3.269), (N=15)
	No change in communication comfort	average increase **M = 0.87 (SD=5.092)**, (N=131)
	Slight *increase* in communication comfort	average increase **M = -1.40 (SD=9.544)**, (N=25)
	Big *increase* in communication comfort	average increase **M = -11.40 (SD=8.096)**, (N=12)

Discussion

Our results reinforce the importance of student-instructor communication in preventing or alleviating math anxiety. However, feeling comfortable with communicating questions or concerns to an instructor or feeling like your instructor is available is a highly individual phenomenon and we cannot offer a universal solution. On the other hand, remote technologies provide new ways to provide communication opportunities. If we combine remote technology with in-person modes of communication, instructors can expand their availability and allow students to communicate in whichever format is most comfortable for them. The promise of choice emerges in our 2021 free response data.

Modes for Asking Questions during Lecture

Many students feel self-conscious verbally asking a question in front of their peers. One student explained, "I was not comfortable in group settings as I have a learning disability especially in Math and need things shown in repeated fashion which can be embarrassing to ask in a group." A text-based way to ask questions was preferred by many students, one sharing that they appreciate "involvement/communication from students when going through examples," with another conjecturing "almost every day there were students on the discord server asking questions and interacting with each other. I believe this is because many more students use Discord already on a daily basis to interact with their friends, and thus they are more comfortable and familiar with using the app." For some, in-person communication is preferential to a text-based option, with one participant writing about the class-time Zoom chat, "I had more anxiety when wanting to ask a question since it would have been asked in front of the entire class, rather than asking one-on-one with the professor" while another mentioned that the chat was distracting because "the nearly 300 students in the class were treating the class chat as if it were a Discord server."

Ways to Attend Office Hours

During remote learning many students missed the in-person interaction of office hours. One student wrote, "it is nice to be able to physically go to office hours instead of through zoom or email." That being said, students had greater access to online office hours, with one explaining, "It was easier to attend office hours. Therefore, it was easier to get help from professors" and another similarly stating, "given that I may have classes or may not be on campus all the time, having online office hours would be immensely helpful in increasing accessibility."

Conclusion

We encourage instructors to explore introducing multiple modes of communication into live lecture and office hours, weaving together "traditional" options, like raising your hand and asking a question out loud, with novel technology-based options, such as providing students a chat feed for typing to submit their questions. While the instructional challenges brought by the COVID-19 pandemic were unexpected, we have an opportunity to use our newfound experiences and expertise with remote technology to create learning spaces that reflect the individualized nature of math anxiety and provide options to alleviate that anxiety.

Limitations & Future Directions

Our study asked students for retroactive self-assessments, which generally are less reliable than a current self-assessment. In the future we would like to assess math anxiety during a learning experience using wearable technology (e.g. an optical heart rate monitor armband) as well as test the impact of integrating remote communication technologies into an in-person course.

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SUPPORTING PRESERVICE K-8 TEACHERS' CONCEPTIONS OF ADDITION USING A LINGUISTICS APPROACH TO ANALYZING WORD PROBLEMS

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Research has not yet examined how linguistic analysis might be applied to support learners in making sense of the semantic differences amongst the three types of additive word problems (i.e. change, part-part-whole, and compare). The authors conducted an ideation analysis of 400 word problems drawing from systemic functional linguistics theory. The findings resulted in a distillation of language features key to the mathematical processes in the problems, which was introduced to preservice elementary teachers (n=86). Analysis of their work demonstrated their ability to employ the functional metalanguage to describe specific linguistic characteristics associated with each problem type.

Background

The challenges faced by students when solving word problems is well-documented (e.g., Carpenter et al., 1980). In fact, the language of word problems has been found to pose greater obstacles than the computations required to solve them (e.g., Kintsch, 1987). To address this issue, the authors aimed to help preservice elementary teachers (PTs) develop a meaning-based metalanguage: a language for helping students and teachers talk about the functions of language and how it shapes meaning in the subject areas (Halliday & Matthiessen, 2013). Systemic Functional Linguistics (SFL) is a social semiotic language theory that offers such a metalanguage. SFL has been applied to articulate some of the linguistic challenges of word problems in secondary mathematics (Huang & Normandia, 2008) but not in the context of differentiating among types of additive word problems. Thus, this study explores how linguistic analysis might be applied to support PTs in making sense of additive word problems.
Van de Walle and colleagues (2019) categorize addition and subtraction problems into four disjoint situations: change-join, change-separate, part-part-whole, and compare. For the purposes of this paper, we use the singular term "change" to refer to problems involving an action that causes a set to undergo an additive increase (join) or decrease (separate). Part-part-whole (PPW) problems partition the relationship amount (a set) and into two disjoint subsets, whereas compare problems involve the additive comparison of two sets. See Table 1 for a sampling.

Research has not yet examined the ways in which metalanguage might be applied to support K-8 preservice teachers (PTs) in making sense of the semantic differences amongst these problem types. Therefore, our research team pursued the following two questions: 1) What linguistic patterns exist in one-step additive word problems? 2) How can PTs use metalanguage to identify the semantic differences amongst additive word problems? This paper expands upon Welder et al. (2021), which reported initial results of this study.

Table 1

Sampling of Additive Word Problems in Introductory Sorting Task

#	Word Problem	Category
5	Javier is collecting **leaves** for a science project. When he started this morning, he *had* 4 **leaves**. After walking through the park, he now *has* 12 **leaves**. How many **leaves** did Javier *FIND* in the park today?	Change
10	The **floor** in Raven's bedroom *is* 88 square feet. She has a **rug** that *covers* 30 square feet of her **floor**. How much of Raven's **floor** *is* **not covered by the rug**?	PPW
13	Marie *USED* 2 **pounds of tofu** to make a stir-fry dinner for her family. She now *has* 4 **pounds of tofu** left in the refrigerator. How many **pounds of tofu** did Marie *have* before she made dinner?	Change
20	One of my kitties, **Azraehl**, *weighs* 13 **pounds** and the other one, **Ezekiah**, *weighs* 9 **pounds**. How much heavier *is* Azraehl than Ezekiah?	Compare
21	Jonah's daughter has *GAINED* 14 **pounds** since she was born. She now *weighs* 22 **pounds**. How much did Jonah's daughter *weigh* when she was born?	Change

Methods

The sample for this study included (n=86) undergraduate K-8 PTs in a 300-level mathematics problem-solving course designed for education majors. The course focused on supporting PTs in developing conceptual meaning for the four operations in the context of word problems. A set of interventional lessons developed through this research project was implemented by two instructors across three sections of this course. Data collection and analysis were conducted in two phases: 1) analysis of word problems to develop the interventional lessons, and 2) implementation of the interventional lessons and analysis of resulting student work.

Development of the Interventional Lessons

Word problem analysis. First, using a corpus of 400 one-step additive word problems, our research team conducted an ideation analysis, examining taxonomic relations of participants, process types, and connectors (Martin & Rose, 2003). *Participants* refer to the nouns or noun phrases in a word problem. Some participants will be quantities, meaning that they have "the quality of something that one has conceived as admitting some measurement process" (Thompson, 1990, p. 4). To distinguish between contextual participants and quantities that need to be considered and reasoned about in the word problem, we used the term *referents* (bolded in Table 1). The term *processes* refers to verbs and verb phrases (italicized in Table 1), and *connectors* comprise of conjunctions or phrases that convey relationships between clauses (underlined in Table 1). These initial analyses resulted in a distillation of language features key to the mathematical meanings of the three types of additive word problems: *time markers* and *active processes* in change problems; hierarchical *relations* amongst referents in PPW problems; and *connectors of comparison* in compare problems.

Linguistic patterns in one-step additive word problems. The analysis indicated distinct linguistic patterns across the three types of additive word problems. Change problems involve one referent being tracked as it changes, or is acted upon, over time. This change causes either an additive increase or decrease in the quantity of the referent. In change problems, the process moves from stasis into action and back to stasis as the referent is being acted upon. For example, in Table 1, problem #13 refers to Marie having a number of pounds of tofu which is decreased when she uses some to make a stir-fry dinner. The processes "has" and "have" are static verbs that indicate no change in the quantity of the referent. An active process is conveyed when Marie "used" the tofu, indicating an additive decrease in the quantity of tofu. Furthermore, because actions happen over time, change problems utilize *time markers* that often serve to differentiate distinct stages in the problem with indicating language such as "then/now," "before/after," etc.

Compare problems include two unique referents and assess how these two quantities compare additively. These problems include comparative connectors, or words such as "more/less than" or "greater/fewer than." Comparative connectors are dependent upon the characteristic being measured. For example, in problem #20 (see Table 1), the referents compared are the weights of two different cats. Because these referents cannot represent the same quantity at two different times (i.e., before and after some event occurred), it is unlikely for time markers to appear in compare problems and the processes are typically static in nature.

PPW problems include three referents that are situated in a specific hierarchical fashion. Two of the referents are subsets of the third overarching referent. These "sub-referents" illustrate one way in which the items in the overarching referent can be broken into two inclusive and disjoint subsets according to some differentiating characteristic at one point in time. Thus, time markers are typically not used and the processes tend to be static.

The results of this analysis informed our design for an instructional intervention. Instructors implemented a series of lessons that introduced the metalanguage of *participants, referents, processes*, and *time markers* during PTs' initial exploration of additive word problem types.

Implementation of the Interventional Lessons

The invention occurred immediately after PTs completed an introductory task in which they were asked to analyze and sort 22 one-step additive word problems into categories based on any similarities and differences they noticed amongst the problems. The instructions for this sorting task were intentionally vague to support PTs' mental constructions through inductive reasoning instead of providing them with category names and descriptions (e.g., Eli et al., 2011). PTs were instructed to investigate the language used in each problem to create at least two disjoint categories based on any patterns that they noticed. PTs completed this work individually outside of class to prevent them from being influenced by their peers' observations. Similar to what we had found when using this task in prior semesters, approximately 70% of the PTs sorted the 22 problems into two categories: addition and subtraction, only considering the operation required.

Following this initial sorting activity, instructors introduced the metalanguage of *participants*, *referents*, and *processes* and as a way for PTs to analyze the word problems based on the meaning of the language used in them. After these terms were introduced to the PTs, they were asked to consider three word problems (one of each type) to highlight the fact that each of the problems can be solved using addition, yet the operation is used in different ways to address a variety of situations (i.e., change, PPW, and compare situations, though not explicitly revealed to PTs at this time). After working together in class to identify the *participants, referents,* and *processes* in these problems, the PTs were then asked to apply this SFL metalanguage to find new ways of sorting the original set of 22 word problems, again, outside of class time. Iterative cycles of this work continued, further honing what naturally emerged in the PTs' categorizations. During these discussions, the idea of *time markers* was introduced to help distinguish between situations that are happening at one point in time (i.e., PPW and compare problems) and those involving changes occurring over time (i.e., change problems). By the end of the lessons, PTs had *inductively* arrived at the distinguishing characteristics underlying the three taxonomic categories of additive word problems based on their attention to the linguistic patterns (and the categorization of the 22 word problems within these groups), at which time the instructors introduced the vocabulary related to each category (i.e., change, PPW, and compare).

Analysis of Student Work

PTs' work collected from these lessons formed the basis of our data collection. After the completion of the interventional lessons, PTs were asked to reflect on the challenges they faced during the lessons in categorizing the word problems and articulating the semantic differences they found across the word problems. The first source of data came from a post-intervention reflection question where PTs were asked to: "Identify the 2-4 word problems that you found most challenging to classify and explain your thinking about them. What made them challenging or what are you left wondering?" The initial, iterative, constant comparative analysis (Strauss & Corbin, 1997) of PTs' responses identified the types of word problems PTs struggled with, as well as reflections that mentioned SFL metalanguage. Each response was coded by type of word problem identified and SFL metalanguage used. Initial findings indicated that PTs struggled less with identifying compare problems and showed more difficulties distinguishing between change and PPW problems. Thus, our analyses from this point on focused on PTs' use of metalanguage to identify the semantic differences between change and PPW problems.

Five weeks after the interventional lessons, participants completed a midterm video reflection in which they were asked to, "explain the difference between addition/subtraction problems that have a change structure and those that have a PPW structure." Transcripts from PTs (n=86) were analyzed for metalanguage articulated by the PTs. In this next round of analysis, researchers added notations regarding how the PTs applied SFL metalanguage to describe the features of the different word problem types. The research team discussed those notes and iteratively developed more refined descriptions of those patterns of application, which comprise our findings.

Findings

PTs' Use of SFL Metalanguage to Analyze the Language of Additive Word Problems

Analysis of PTs' work demonstrated an ability to employ the metalanguage to describe specific linguistic characteristics associated with different additive word problem types. PTs were able to use metalanguage to 1) distinguish between contextual participants and referents, 2) identify the number of referents and use this knowledge to classify problem types, 3) identify active versus static processes and apply this knowledge to distinguish between change and PPW problems, and 4) identify time markers in change problems. In what follows, we showcase PTs' responses to illustrate how they used the SFL metalanguage to identify challenges, and in turn key features, of the additive word problems. When quoting PTs our nomenclature reflects the instructor of the class the student was enrolled in (author A or R) followed by a student number.

Referents versus participants. Although PTs initially found it challenging to identify the referent(s) amongst several participants in a given word problem, the metalanguage of *referent* versus *participant* helped PTs identify patterns in the word problems. PTs inductively identified a categorization scheme, separating the problems with one referent (i.e., change) from those with two referents (i.e., compare) and three referents where two sub-referents are encapsulated in one major referent (i.e., PPW). In turn, the identification of the number (and organization) of referents became a key feature PTs analyzed for when categorizing additive problems.

For example, at first, one PT stated that particular word problems were challenging because, "I was not able to identify the correct number of referents. This was because the wording was difficult to decipher" (R11). However, the same PT later explained that "part-part-whole has two referents essentially that come together to make one larger overarching referent" (R11).

Active versus static processes. PTs initially articulated challenges in identifying processes as being static or active, but this developed into a tool they later used to help distinguish between problem types. During the sorting activity, the metalanguage of static versus active helped PTs identify patterns in the word problems based on their *processes*, inductively categorizing the problems with active processes (i.e., change) separately from those with static processes (i.e., compare and PPW). For example, when reflecting on problem #10 (see Table 1), a PPW problem, which typically involves static processes, this PT considered if the process "cover" was active or static, which helped her determine that the problem was PPW and not change:

> I was unsure whether or not to consider the verb 'cover' as an action or stasis verb since it was a rug doing the action. I put it as an action verb… but I changed it...because the rug is not doing the action, it is a stasis verb (R14).

Later in this PT's midterm reflection, they showed a deeper understanding of the role of active and static processes, particularly their role in change problems, articulating:

> A change structure is when there's some sort of action that is occurring that's changing the result. So, you're going to go from the past to some sort of action that occurs to now.

> And so basically, it’s going from a stasis standpoint to an action and then stasis. Then that action that is happening in the middle is either adding if it’s an addition problem or taking away, if it’s a subtraction problem from the result (R14).

In this explanation, the PT notes several key features of the *processes* within change problems: 1) change problems indicate a change in a referent’s quantity, 2) a relationship exists between time markers and the type of process, i.e., that time markers indicate a change over time in which the *process* moves from stasis to active and back to stasis, and 3) the active process denotes either an additive increase or decrease in the resulting referent.

Time markers. Last, attending to the metalanguage of time markers helped PTs identify change problems. Most PTs were able to identify time markers, but some struggled to determine the timing of events in a word problem. For example, one PT explained their challenge with problem #5 (see Table 1) as: “The wording in problem 5 is confusing because it is not clear if the first four leaves that Javier found were in the morning or the day before” (A3).

Other PTs considered what they observed to be a conflicting presence of other key features in addition to time markers. For example, in problem #21 (see Table 1), one PT seemed to have identified the time markers (i.e. “since” and “now”) but wrestled with situating these time markers in what the PT had identified to be multiple referents: “The question was being asked over a period of time, however, it was challenging for me because it could have also gone under the category of a part-part-whole question” (A22). Therefore, although time markers did overall seem to be quite helpful for PTs in distinguishing among types of problems, they still needed to situate this knowledge with other key features that were sometimes misidentified.

By the midterm reflection, however, most PTs did note that time markers were a significant key feature in change problems. For example, one PT noted:

> I guess you’d say that there’s like a, what is it, a time, in time change? No, like a time marker. And so, you can tell that that problem is a change if it has, like before, after now, or later there, or just something that indicates like that it had changed (A36).

Discussion

The language of mathematical word problems can greatly influence how students make sense of situations posed and identify appropriate solution strategies, which vary according to the type of word problem they are being asked to solve (e.g., Carpenter et al., 1988). PTs need tools for unpacking the language in word problems so they (and their future students) can access their mathematical meanings. One option is an accessible metalanguage—one that targets the most salient or challenging linguistic features of those word problems. The findings presented here demonstrate how a targeted application of SFL metalanguage can succinctly describe the linguistic features that articulate the key mathematical functions in additive word problems and how such a targeted approach can support PTs' abilities to apply this metalanguage in accurate and purposeful ways. Participants were able to utilize the metalanguage to identify key semantic features of each type of additive word problem, enabling them to focus on the key *functions* in additive word problems, rather than identifying "keywords" to identify operations (such as "altogether"), a strategy that has been shown to be problematic (Huang & Normandia, 2008).

This linguistic knowledge forms a foundation for teachers in making instructional decisions in selecting and posing word problems for their students. Equipped with this understanding of the relationship of language and mathematical processes, educators can design more informed lessons that can help students to wield this knowledge to categorize, write number sentences for, solve, and pose a variety of word problems. This work may also inform how teachers and teacher educators can compose word problems to more clearly mark linguistic features to support their future students' understanding of the meaning underlying the operations they will teach.

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EXAMINING PROGRAMATIC LESSON STUDY IN PRESERVICE TEACHER EDUCATION

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This study of mathematics preservice teachers investigates their experiences with a program *requirement to learn about and engage in multiple iterations of open approach lesson study. Inductive analysis revealed four experiential themes: Variable Contexts, Professional Community, Challenges, and Transformation. Preservice teachers attribute their transformation to reform-based mathematics instruction involving iterative experiences and processes of open approach lesson study. Other experiences and implications are examined.*

Teachers are the critical instructional element in the classroom (National Council of Teachers of Mathematics [NCTM], 2000). They manage instructional norms, discourse, tasks, and tools (Franke et al., 2007). They are also expected to deeply understand mathematics, mathematics pedagogy, and potential outcomes for students. Professional learning should support teachers to establish effective instructional contexts and adapt to new challenges. One such form of professional learning is called lesson study. Lesson study originated in Japan and has been used by in-service teachers (ISTs) across the world (Stigler & Hiebert, 1999). More recently, teacher educators have begun involving pre-service teachers (PSTs) in the lesson study practice. Lesson study provides an authentic window for researchers to view teacher professional learning (Matney et. al, 2020). Although there are studies that share about PST's doing short bursts of lesson study in courses (Angelini & Alvarez, 2018; Guner & Akyuz, 2020; Roberts et. al., 2017), this study takes a wider look at the possibilities of integrating lesson study in PST learning throughout each year of the program. As such, this study fills a need for research looking at impacts of lesson study when it is incorporated throughout a mathematics education program.

Relevant Literature

Lesson Study and Initial Teacher Education

In 1999, *The Teaching Gap,* called for lesson study to be tried and tested in the United States (Stigler & Hiebert, 1999, p. 131). Following this call, several researchers have shown that when lesson study is implemented well and for sufficient duration, similar results to Japanese lesson studies are found (Lewis & Hurd, 2011; Lewis et al., 2009). Lesson study engages teachers in a "comprehensive and well-articulated process for examining practice" (Fernandez et al., 2003, p. 171). The lesson study approach is a method of professional learning that encourages teachers to reflect on their practice through a cyclical process of studying curriculum and setting goals, collaboratively planning a research lesson, observing the research lesson being taught, and reflecting on student learning (Lewis et. al., 2009). Research has shown that district support, lesson study has built strong professional learning communities within schools, resulting in instructional improvement and increased teachers' knowledge (Stewart & Brendefur, 2005).

Lesson study has most commonly been utilized for developing ISTs, however, many universities have begun to implement this practice in their initial teacher education (ITE) programs as a method for training and developing PSTs. Although ITE programs often focus on reform-oriented pedagogy, PSTs are exposed to traditional, lecture-based practices in many of their field experiences (Post & Varoz, 2008) causing disconnect between theory and practice (Cheng, 2011; Fernandez & Robinson, 2006). Sims and Walsh (2009) state that "Learning from teaching is a critical component of successful teacher education" (p. 732), however, passive observation of traditional teaching is not providing PSTs the opportunity to do so. On the other hand, the collaborative nature and debriefing elements of lesson study supplement the learning of best practices that PSTs undergo in their undergraduate coursework (Roberts et al., 2018). Additionally, the emphasis of collaboration rooted in lesson study improves the pedagogical knowledge of teams of teachers rather than individuals (Rappleye & Komatsu, 2017). Lesson study is an avenue in which PSTs can engage in meaningful learning through collaboration, teaching, observation, and reflection that will help bridge the gap between theory and practice (Angelini & Alvarez, 2018).

Open-Ended Approach & Open Approach Lesson Study

Important to the context of the study is the pedagogical idea of the open-ended approach for teaching mathematics through problem solving. Open-ended approach was originally researched in Japan as a method to evaluate higher order teaching skills and then for potential to improve teaching and learning (Becker & Shimada, 1997). Open-ended approach is a student-centered teaching practice in which the teacher poses a problem to students that has many possible solution paths or multiple correct answers. These open-ended problems are designed to be accessible and sufficiently challenging to students at all levels (Munroe, 2015). Becker and Shimada (1997) found that teaching which utilized open-ended approach allowed students to develop knowledge and skills as components of higher order thinking.

We use the term, open approach lesson study, to denote the kind of lesson study in which open approach is used in the design of the research lesson. Researchers have found open approach lesson study to engage teachers in critical reflection that shifts their long-held beliefs that lecturing is a sufficient means to teach mathematics, and begin forming new beliefs about the effectiveness of more student-centered approaches to teaching (Inprasitha & Changsri, 2013). Inprasitha (2006) found that open approach lesson study also changes and develops PSTs views of teaching and learning. Inprasitha noted that PSTs developed a broad view of teaching in which teaching mathematics is more than just covering the content, rather students' learning processes, ideas, and attitudes towards mathematics are emphasized.

In this study, we inquire about PSTs programmatic experiences as they learned about and enacted open approach lesson study. We do this to build upon the current research literature about this practice in the context of initial teacher education. By doing so, we hope to illuminate the perspectives of those who are learning about what it means to be a mathematics teaching professional through a program focusing on open approach lesson study. In what follows, all references to lesson study infer the contexts of mathematics and open approach lesson study.

Method

The study here was a phenomenological qualitative investigation about PSTs experiences of lesson study during their five-year undergraduate mathematics education program. The program includes course-based learning about open-approach lesson study in years one through four, including some time observing lesson study. In year five, the PSTs conduct weekly lesson studies during their yearlong internship.

Participants and Context

Participants were recent graduates and professors of an undergraduate program at a university in Southeast Asia. The PSTs participants were in a program that certifies mathematics teachers to teach all grade levels, K-12. The participants described their K-12 educational experiences as traditional, in the sense that their mathematics classroom experiences involved lecture-based teaching about mathematical processes that were then to be memorized and used to solve exercises. Their first experience with reform mathematics education involved learning about teaching through problem solving (open approach) during their initial teacher education program. Participants were selected for the study based on three key criteria. First, they must have completed the program in its entirety. This enabled the participants to offer holistic perception of the role and experience of lesson study during the program. Secondly, the participants must have continued to teach, or continued their study of teaching, post-graduation. These criteria were chosen to inform the research about connections between the lesson study experience as an undergraduate and their identity as a teacher. Thirdly, the participants were proficient in English so that they could clearly articulate their thoughts and ideas about the lesson study experience to the researchers. In order to certify participants met the criteria of the study, we consulted with mathematics education faculty of the university. Twenty-four program completers agreed to be participants. Furthermore, two current mathematics teacher educators holding PhDs and who currently teach about lesson study in the program agreed to be participants, in the sense that they could offer insights on the program and help in the selection of participants. All names of participants are pseudonyms. The study was approved by the IRB.

Data Collection and Analysis

We conducted in-depth interviews with each PST participant. The interviews were conducted in English. Each interview was audio recorded and transcribed for textual analysis. We modeled our inductive thematic analysis from Hatch (2002) as a systematic procedure for coding data. Data statements were analyzed and categorized into salient themes that represented the phenomenon of interest, i.e., PSTs programmatic experience of open approach lesson study. Throughout the analysis procedure, we attended to the trustworthiness criteria for qualitative research recommended by Lincoln and Guba (1985) and Nowell et. al. (2017).

Findings

Inductive analysis revealed four themes involving PSTs experience of open approach lesson study: experiencing variable contexts, experiencing professional community, experiencing challenges, and experiencing transformation.

Experiencing Variable Contexts

As PSTs were going through the program, they experienced learning about open approach lesson study in various ways. They began hearing about lesson study in coursework and their mathematics education professors were engaging them in mathematical learning through open approach. They were given assignments to plan tasks and events together that followed the lesson study process such as Children's Day and Math Camp. PSTs had the opportunity to go with their professor to see an open lesson occur at a school. These events occurred in the early years of the program and gave PSTs initial notions about lesson study.

However, the PSTs noted that these notions did not coalesce for them until their internship when they enacted lesson study with their mentor teacher/team multiple times. Once the PSTs reached their internship, they enacted the lesson study process for each lesson. They revealed that several aspects of the lesson study format were different for each one of them. These aspects included, team size, who was on a team, who was planning, who was observing, who was reflecting, and how often reflection occurred. These differences were accounted for by each of their school's unique context. Teacher and school schedules would often determine who could be on a team, who was available for planning, observing, and reflecting. Some teams would reflect immediately after the lesson. Other teams would reflect after school. Another school's context dictated that PSTs reflect once a week on the series of lessons and that reflection was led by the principal. Though the PSTs all experienced variable and different organizational features, their descriptions all revealed that the main aspects of lesson study (research, plan, enact, and reflect) persisted.

Experiencing Professional Community

The PSTs each revealed that lesson study gave them a rich and vibrant way to learn about teaching from a professional community. PSTs came to see a real power in doing the four steps of research, plan, enact, and reflect as part of a community and described that they would feel alone in the classroom without lesson study. Their experience of lesson study has awakened them to understand that alone, teachers cannot see everything that is important. Amy shared, "Even if there are only five students in the classroom… I cannot see [all] five students in every process in the classroom. So, we can share the opinion and view with the teachers in the team" (Interview, December 18, 2019). The PSTs valued the ideas and alternative points of view that ISTs on the team provided and attributed that as a factor in their growth. Participating in lesson study with a professional community also strengthened PSTs communication skills. Lesson study allowed PSTs to learn how to effectively share their ideas about students' mathematical thinking. Furthermore, conducting lesson study with ISTs deepened their knowledge of the students. The multiple perspectives allowed the PSTs to gain better insight on all students' learning, not only the select students they could observe individually. Additionally, ISTs often contributed a longitudinal perspective about students. According to Cathy, when reflections occurred, mathematics teachers who had her students before chimed in; "they will share something that they know about the students with me" (Interview, December 16, 2019). Moreover, the lesson study process provided a supportive professional community that opened a space for PSTs to think through the development of the problem situation and the lesson plan relative to their particular students.

Experiencing Challenges

The prior K-12 learning experiences of the PSTs were described as vastly traditional, which they explained as teaching directly from what the textbook says. For this reason, the PSTs found the planning phase of lesson study challenging, since they were moving beyond the textbook to anticipate student interests and open-ended ideas about the mathematical problem. In the traditional approach, there was less feedback during instruction about what students found interesting. As PSTs sought to plan the problem-solving situation using open approach, they saw the need to draw on deeper knowledge about who students were. Having few experiences with the need to connect students to mathematics made this specific part of planning demanding. In the traditional approach, each teacher developed the flow of the lesson strictly according to the textbook and consensus with other teachers was not seen as a necessity. However, when conducting lesson study, team consensus on the research lesson plan is important. The PSTs recognized there was sometimes difficulty in coming to consensus about each element of the research lesson. PSTs explained that sometimes the ISTs have a different idea, and the team goes with that idea because the ISTs have more experience. The PSTs recognized the challenges that arose from engaging in lesson study took time to overcome, but they considered the time spent in the process a valuable effort for their professional growth.

Experiencing Transformation

The PSTs reflected upon how their experiences with open approach lesson study transformed their beliefs and abilities involving teaching mathematics. PSTs explained that teaching mathematics during internship would have been isolating without the lesson study process. Alone, the PSTs felt they would have reverted to teaching exclusively by lecture via the textbook. Cathy exemplifies this sentiment when she discusses that without lesson study “I would have read the textbook and told them the concept that I wanted them to know in my class; the same way that that I was taught” (Interview, December 16, 2019). The PSTs attributed their transformation to having a professional community through open approach lesson study and to having experienced the process many times throughout their program. They each shared that they teach differently form the way they were taught and that these transformations occurred because of the positive learning they observed from their students in their many research lessons.

Discussion

We note that each PSTs experience during internship had the same lesson study frame of study, plan, teach, and reflect (Lewis et. al., 2009) but was enacted differently according to their school context. In spite of these differences, the PSTs perceive the same kinds of positive impacts and challenges from their involvement in lesson study. Furthermore, the program in which these PSTs where learning provided direct opportunity and intentional connections to lesson study prior to internship and this provided a solid basis to understand and enact lesson study with a professional community. The PSTs went into internship with strong notions of working as a community to overcome professional challenges and this in turn supported their transformative experience. These findings connect with previous research findings showing that with time and school support, lesson study has built strong teacher professional learning communities within schools (Stewart & Brendefur, 2005). In other words, the understanding and multiple enactments of open approach lesson study throughout the program helped the PSTs not fall back into traditional teaching tendencies (Owens, 2013). Furthermore, the findings here support Fernandez et al.'s assertion that lesson study is a "comprehensive and well-articulated process for examining practice" (2003, p. 171). Open approach lesson study helped the PSTs to connect theory and practice, overcoming an important dilemma noted by prior research (Cheng, 2011; Fernandez & Robinson, 2006). The process of researching, planning, teaching, and reflecting as a professional community allowed them to move from seeing learning only occur from traditional forms of teaching and into teaching through problem solving. The PSTs were given multiple opportunities, as both the observer and the teacher, to experience student learning through problem solving. These experiences acted as authentic verifications of a methodology that moved PSTs from the theory of teaching through problem solving into practitioners of teaching through problem solving (Matney et. al, 2020). In conclusion, the program's inclusion of open approach lesson study provided a professional space through which PSTs learned about the processes of teaching, critically examined student learning, and hence transformed their own teaching practice.

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