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Better Together: Mathematics and Science Pre-Service Teachers' Sensemaking about STEM

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ABSTRACT: While the perspectives and practices of many educational stakeholders in relation to STEM have been documented, research has yet to deeply explore pre-service teachers' (PST) understandings and how to support their sensemaking about STEM during pre-service teacher education. To address this, we used two STEM integration frameworks, focused on discipline-based practices and modeling with data, to inform the design of a STEM unit that brought together thirty secondary mathematics and science PSTs. With an eye on PSTs' development of a situated understanding of STEM, a qualitative analysis of pre/post surveys and STEM lesson sketches revealed that PSTs collectively shifted from initial views of STEM as blurred lines between subjects to a more nuanced understanding of where and how subjects cross and meet. PSTs also described STEM activities through a more plausible understanding of student and teacher actions and viewed data as a bridge to connect disciplines and the real-world. Furthermore, PSTs' descriptions of anticipated challenges to planning for and implementing STEM mirrored those of in-service teachers. We discuss these findings through the lens of sensemaking theory, highlighting shifts in the sum of PSTs' individual understandings to a more collective and situated understanding of STEM. We also discuss implications focused on the role of data in STEM activities and the affordances of secondary mathematics and science PSTs sensemaking together to about STEM.

Keywords: STEM integration, Pre-service teacher education, Mathematics education, Science education, Teacher sensemaking

1. Introduction

The ways in which educational stakeholders understand the meaning of STEM (Science, Technology, Engineering, and Mathematics) is highly varied, causing STEM to be ambiguous in nature and teachers to experience challenges bringing STEM into their classrooms (Akerson et al., 2018; Holmlund et al., 2018; Margot & Kettler, 2019; Mejias et al., 2021). To clarify the ambiguity around STEM, some in the field of education have worked to define STEM through the integration of disciplines that results in a framework for STEM education (e.g., English, 2016; Kelley & Knowles, 2016; Mejias et al., 2021). In these STEM frameworks, content integration is explicit, discipline-based practices work together, activities are ambitiously implemented, and ideas are connected across subjects and embedded in the world around us (NRC, 2014). However, even with these STEM frameworks, the variability in how STEM is understood makes it imperative for "those working in the same system… explore the common elements that are being attributed to STEM education and co-construct a vision that provides opportunities for all their students to attain STEM-related goals" (Holmlund et al., 2018, p. 17). This call for a shared understanding of STEM within local systems is reiterated by Dare and colleagues (2019), indicating a shared understanding (i.e., common language and conceptualization) can help stakeholders better communicate and productively bring STEM into classrooms.

In past research, STEM perspectives and practices of many stakeholders, particularly in-service teachers, have been explored (e.g., Akerson et al., 2018; Allen & Penuel, 2015; Breiner et al., 2012; Herro & Quigley 2016; Ring et al., 2017). However, we know little about how pre-service teachers (PSTs) understand STEM prior to entering the profession and how teacher educators can productively support PSTs' understandings about STEM. Studies that have explored how PSTs understand STEM indicate a similar variation to that of other stakeholders and call for more effective STEM instruction during PST education that helps to "show them the way" (Radloff & Guzey, 2016, p. 771). Furthermore, given the attention to STEM education and recent calls for a greater focus on the integration of STEM subjects (e.g., English, 2017; Mejias et al., 2021; Tytler, 2020), it is important to understand how mathematics and science PSTs' make sense of STEM. It is equally important to understand how teacher education can support the sensemaking process, as sensemaking about STEM has brought coherence and confidence to in-service teacher STEM implementation (e.g., Allen & Penuell, 2016; Davis et al., 2020) and sensemaking has the potential of helping them demystify the meaning of STEM and develop a plausible understanding that informs their future classroom practice. Thus, the purpose of this study is to understand and support secondary mathematics and science PSTs' sensemaking about STEM and STEM integration.

2. Conceptual framework

Often our past and current experiences exist in conflict, causing us to either make sense of current situations through previous experiences or renegotiate our understanding based on the current context and develop greater coherence to a given issue (Ancona, 2011). Teacher education can be viewed as a site for PSTs to build coherence around the ambiguities in teaching and learning, as PSTs often bring experiences that can be leveraged as an opportunity for sensemaking (Davis et al., 2020; Fullan & Quinn, 2015). Therefore, we approach this study with the view that mathematics and science PSTs are sensemakers (Spillane et al., 2002; Weick et al., 2005), constantly creating, interpreting, and negotiating the meaning of mathematics and science teaching and learning.

In general, sensemaking is how we structure ideas and create a "plausible story" to enact (Weick et al., 2005, p.410). This plausible story is further understood through a cognition-oriented perspective that considers individual cognition and situated cognition. Here, individual cognition refers to one's noticing and interpretation of meaning and understanding based on prior knowledge, beliefs, and experiences (Spillane et al., 2002). In contrast, situated cognition refers to the social and contextual aspects that are introduced when individuals work in an organization or community, where context is viewed as a central element in the sensemaking process (Spillane et al., 2002).

With sensemaking being inherently collaborative (Ancona, 2011), the link between an individual negotiating a plausible story and situated cognition is that sensemaking occurs on two interacting levels—the individual and the collective (Spillane et al., 2002). Individual understandings are shaped by one's prior knowledge, context, and activity with the collective. However, the individual's impact on the collective's understanding is not straight forward, as it is further situated by the context (i.e., the learning community and the resources available to them). Additionally, due to the individual and situated notions of cognition, sensemaking can result in a range of meanings and actions (e.g., Allen & Penuel, 2015; Cohen & Hill, 2001). For the purposes of this paper, we focus on the understanding of the collective (i.e., the sum of all individuals' understanding), drawing inferences on how a group of PSTs come to understand in the context of a pre-service teacher education STEM unit.

3. Background

3.1. Models of STEM integration

STEM integration is an effort to combine disciplines in authentic classroom activities (Moore et al., 2014) and a variety of models exist (e.g., Breiner et al., 2012; Brown et al., 2011; English, 2016). Most notably, the NRC (2014) describes how STEM integration occurs in school-wide and after-school initiatives, where teachers either bring together at least two subjects (e.g., mathematics and science), a practice and a content domain (e.g., engineering practices and geometry), or two discipline-based practices (e.g., mathematics and science practices) as a way to achieve STEM integration—underscoring the diversity of STEM conceptualizations and ways in which this integration is carried out in educational contexts.

Narrowing our focus, we use two views of STEM integration that can support mathematics and science PSTs' sensemaking. First, Kelley and Knowles (2016) describe a conceptual framework for STEM education where teachers and students use science inquiry, technological literacy, mathematical thinking, and engineering design to engage in situated STEM learning. They also describe the critical nature of the physical and social context for learning and imagine STEM integration through discipline-based practices and ways of thinking. Second, English (2016) highlights the challenges of attending to multiple disciplines during STEM integration, where often mathematics and engineering take a diminished role in the enactment of STEM learning activities. Her solution is to frame STEM integration through activities where students engage in engineering-based modeling with data—a notion also suggested by Lehrer and Schauble (2020). Further, English frames STEM using four increasing levels of integration—disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary. Briefly, *disciplinary integration* describes how "concepts and skills are learned separately in each discipline," *multidisciplinary integration* describes how "concepts and skills are learned separately but within a common theme," *interdisciplinary* deepens integration through "closely linked concepts and skills learned from two or more disciplines with the aim of deepening knowledge and skills," and *transdisciplinary integration* describes how "knowledge and skills learned from two or more disciplines are applied to real world problems and projects" (English, 2016, p. 2).

With these two framings, PSTs can begin to envision and make sense of STEM integration through familiar concepts like discipline-based practices and data modeling. This also aligns with current mathematics and science content and practice standards (CCSSM, 2010; NGSS, 2013), as both sets of standards center practices and modeling with data.

3.2. Perceptions and challenges of implementing STEM in mathematics and science

To describe how STEM plays out in educational contexts, Akerson and colleagues (2018) determined that there is not an overarching *nature of STEM*, but rather STEM is made up of the individual natures of each discipline. With this in mind, teaching STEM in a single-discipline classroom can be near impossible because teachers lack enough time to teach each integrated subject's content and they have not been trained in the content and pedagogy of disciplines other than their own. The lack of a clear *nature of STEM* furthers the conceptual ambiguity around STEM integration and begins to reveal the practical challenges teachers encounter when trying to implement STEM in their single-discipline classrooms.

The prevalence of disciplinary and multidisciplinary perspectives on STEM integration may be due to the challenge of enacting STEM in an interdisciplinary or transdisciplinary way (Akerson et al., 2018). Furthermore, in-service teachers often view STEM as a fundamental shift in their instructional practice and typical school structures (i.e., single-discipline courses) tend to lack a culture of collaboration across disciplines, creating challenges to successful STEM enactment (Margot & Kettler, 2019). Teachers may also find it difficult to manage different forms of discipline-based reasoning and practices because managing two or more sets of knowledge can exacerbate the challenges that already exist for teachers (Lehrer & Schauble, 2020). Being aware of the challenges around STEM are important to know and will help to overcome these challenges in the future.

Advancing our understanding of how teachers engage in sensemaking about STEM integration, Allen and Penuel (2015) conducted a longitudinal study of science teachers sustained sensemaking about NGSS and STEM in a professional development context. By engaging in discussions and STEM related activities over an extended period, they suggest that sustained sensemaking should help teachers manage the ambiguity, uncertainty, and perceived incoherence of STEM. Cohen and Hill (2001) also speak to these recommendations and argue that when teachers' have opportunities to learn that are grounded in curriculum and instruction over an extended period, policy is more likely to be implemented after sensemaking.

With this study, we aim to address some of the challenges of implementing STEM education by bringing secondary mathematics and science PSTs together over a sustained period. In doing so, they can discuss the ambiguity around STEM integration, engage in activities together, and learn from each other's discipline-specific knowledge and practices. Additionally, we offered the PSTs quality resources and frame STEM pedagogy as something not too different from the ambitious teaching the course was already preparing the PSTs to carry out. By addressing the challenges directly, PSTs will gain a deeper understanding of STEM integration and a more practical vision for STEM integration in their future mathematics and science classrooms.

4. The present study

Given the ambiguity and challenges around STEM, it is imperative for teacher educators to create productive learning environments and activities that help PSTs develop a coherent understanding and vision. Therefore, the purpose of this study is to understand how secondary mathematics and science PSTs make sense of STEM before and after engaging in collective sensemaking during a STEM unit. The following research questions guide this study: (1) How do PSTs make sense of STEM (in education or generally) before and after the STEM unit? (2) How do PSTs make sense of STEM activities in a classroom context before and after the STEM unit? (3) After the integrated STEM unit, what do PSTs continue wanting to know about STEM and foresee as the challenges for implementation?

5. Methods

We used qualitative methods, drawing on inductive coding techniques in the tradition of constant comparative analysis (Corbin & Strauss, 2015), to understand how a group of secondary mathematics and science PSTs collectively make sense of STEM before and after a STEM unit. This approach is appropriate because the ambiguity around STEM makes it difficult to hypothesize how PSTs conceptualize and envision STEM in a classroom context and using inductive techniques allowed for multiple pathways to emerge based solely on the data. In addition, due to our design, we focused on shifts in the collective, situated understanding of PSTs, rather than shifts in individuals' understanding, as the STEM unit was designed around PSTs sensemaking together.

5.1. Participants and context

The participants for this study include a single case of a group of 16 mathematics and 14 science PSTs. Each PST was enrolled in a either a secondary mathematics or science teaching methods course at a large university in the southeastern United States. Each methods class was a semester-long course that met once a week and combined undergraduate and graduate students participating in four- and five-year teacher preparation programs. Throughout the STEM unit, the students from the mathematics and science methods courses, each taught by two of the authors, were combined to make a single class of 30 PSTs.

5.2. STEM unit design

Following recommendations from the literature, we aimed to provide PSTs with opportunities to explore STEM teaching resources, engage in STEM activities, and both reflect on and discuss the meaning of STEM over an extended period. An important aspect of the STEM unit was its focus on framing STEM integration through discipline-based practices, data-use, and modeling, as each is relevant to mathematics and science education and constitute areas of overlap between mathematics and science content and practice standards (e.g., CCSSM, 2010; NGSS, 2013). Additionally, teachers were often challenged to consider plausible implications for how the ideas/activities being discussed would unfold in a classroom. Collectively, these design decisions resulted in a three-lesson STEM unit.

5.2.1. Lesson 1: Thinking about STEM and starting an example task

After discussing PSTs prior knowledge about STEM through small- and whole-group discussions about "What is STEM", we intentionally grouped mathematics and science PSTs together for an engineering design task, *Chutes-R-Us* (Barron, 1997; Figure 1). Groups worked together to collect, analyze, and model data to form conclusions. Central here was our integration of classroom-friendly technologies to display, organize, and work with data in both small and whole-group discussion—specifically we used Desmos (see https://www.desmos.com/calculator), an online graphing calculator, and CODAP (see https://codap.concord.org/for-educators/), an online data analysis platform. PSTs created visualizations using self-collected data and engaged in conversations about the strengths and challenges of using these technologies with students, further sensemaking about how technology is integrated as both a teacher and student tool in STEM activities.

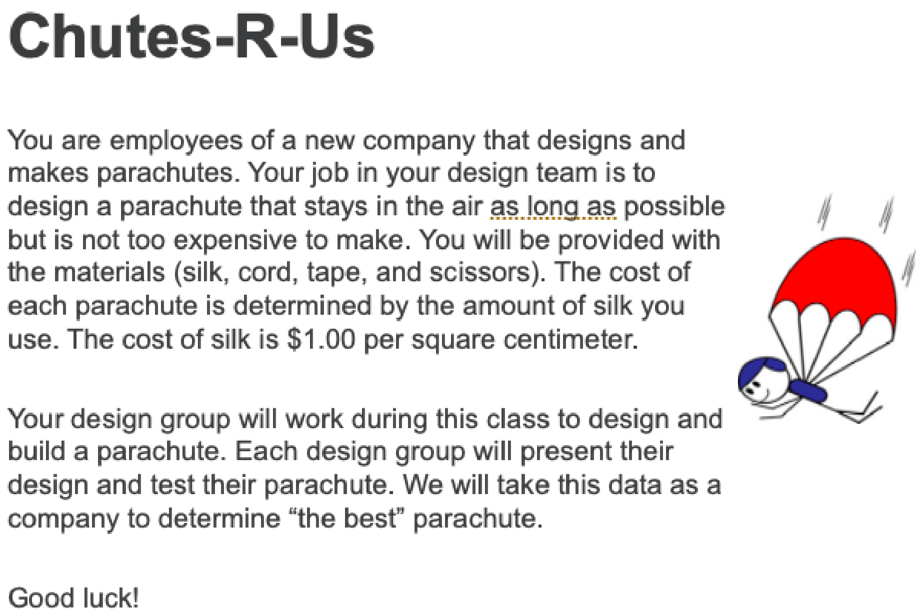

Figure 1. Chutes-R-Us (Barron, 1997)

5.2.2. Lesson 2: Inviting a Geographic Information Systems (GIS) expert

In the second lesson, PSTs learned from a geographic information systems (GIS) expert who exposed them to sample lessons using local data to teach different mathematics and science content standards. PSTs also had time to explore how to navigate and use ArcGIS (see https://www.arcgis.com), an online GIS platform, in their instruction. By introducing PSTs to these GIS resources, they had to make sense of how this technology would be used to facilitate learning in their classrooms, where local data can serve as the catalyst to understand and explore local issues through mathematics and science concepts.

5.2.3. Lesson 3: Wrapping up and cross-over lesson sketches

Prior to class, PSTs completed an assignment where they used Desmos or CODAP to analyze the class dataset (developed in Lesson 1) and form conclusions about what would constitute *the best* parachute for the company. In class, we modeled the process of facilitating a class discussion and using data to form conclusions, focusing conversations around effective use of data visualizations using technologies previously introduced. The class then recapped the *Chutes-R-Us* activity and situated our understanding by thinking about potential benefits and challenges around for implementation in a classroom context.

After closing the activity, we placed PSTs in groups (at least one mathematics and science PST per group) to create a STEM Lesson Sketch (Figure 2). In these sketches, PSTs were prompted to consider topic, objective, and cross-over, in addition to describing how the lesson would be enacted, what challenges they would anticipate, and any external sources or materials they needed. Overall, the lesson sketches provided an opportunity for PSTs to apply their sensemaking about STEM and think through how this new plausible understanding would playout in a classroom context.

Cross-Over Partner STEM Lesson Sketch

Names:

Subjects taught:

Topic and Cross-over:

Objective/Outcome:

Please describe the following:

1. Links to any sources (particularly GIS maps or data used):
2. Materials needed:
3. Steps to the lesson implementation and overarching question:
4. Challenges you anticipate during this activity. How might you address them?

Figure 2. Cross-over STEM Lesson Sketch template

5.3. Data sources and procedure

Data were collected using an open-ended survey with three items and lesson sketches. The survey questions were specifically designed to capture data that would inform the three research questions (Table 1) and PSTs completed the survey at two time points—once before starting the STEM unit, indicating PSTs' prior knowledge, and then again after its conclusion, indicating PSTs' situated understanding. The lesson sketches captured the plausible stories of PST for STEM integration and the challenges they anticipated as they planned for and implemented an integrated STEM lesson.

Table 1. Survey questions' alignment with research questions

Pre/Post-survey questions	RQ alignment
What do you know about STEM? *Your answer can include anything at all— related to teaching and learning or related to general knowledge about it.*	RQ1: How do PSTs make sense of STEM (in education or generally) before and after the STEM unit?
What does a STEM activity look like in the classroom? *Consider what the students and teaching are (or should be!) doing.*	RQ2: How do PSTs make sense of STEM activities in a classroom context before and after the STEM unit?
What do you want to know more about regarding STEM?	RQ3: After the STEM unit, what do PSTs continue wanting to know about STEM and foresee as the challenges for implementation?

5.4. Data analysis

All data were collected without individually identifiable information, meaning the following description of our analyses takes place at the whole-group level, rather than the individual. Overall, the analysis process took place in three phases that assisted in developing themes from the pre- and post-survey data, understanding shifts in PSTs' sensemaking from pre-to-post, and understanding their plausible stories for STEM integration from the lesson sketches. To provide evidence of validity and trustworthiness, all data were analyzed by the authors individually before meeting to discuss discrepancies and agree on all codes and themes at each step in the data analysis. During this process we also developed analytic memos (Saldaña, 2013) to narrate the analysis process and record our decision-making.

In Phase 1, we employed open and *in vivo* coding techniques (Saldaña, 2013; Strauss & Corbin, 1990) allowing us to be descriptive while also staying true to PSTs' voice during the initial coding phase. For example, when a PST said, "A STEM activity in the classroom would involve aspects from multiple STEM areas (so incorporating mathematics into biology). The teacher would be teaching how interconnected the subjects are," we wrote an *in vivo* code of, "teaching how interconnected the subjects are," and an open code of, "blurring the lines between subjects." In Phase 2, we employed axial and selective coding (Saldaña, 2013; Strauss & Corbin, 1990) to put the data back together and make connections between the codes using descriptive categories. The outcome of axial and selective coding produced analytic themes that were then used to answer each research question. During Phase 1 and 2, we also wrote analytic memos after each meeting. In Phase 3, we explored key shifts from pre-to-post, grounded in our discussions of the overall dataset, themes, and analytic memos. Phase 3 also included analyzing the lesson sketches, a proxy for understanding how PSTs understand STEM integration in their practice, using English's (2016) *levels of STEM integration*. Here, we classified the ways teachers were making sense of STEM integration after the STEM unit and applied the previously described coding phases to the lesson sketches to assist in triangulating the findings.

6. Findings

The following sections link findings from the analysis to each of the three research questions. Themes from the pre- and post-data and lesson sketches are first discussed individually before looking at shifts from pre-to-post in the discussion. An overview of themes, organized by research question and pre/post, can be found in Table 2.

Table 2. Descriptions of themes identified before and after the STEM unit

Pre-STEM Unit			Post-STEM Unit		
Theme	*n*	Description	Theme	*n*	Description
RQ1: How do PSTs make sense of STEM (in education or generally) before and after an integrated STEM unit?					
Blurring the lines between subjects	22	STEM is seen as something within and across STEM disciplines included in the acronym.	Where subjects cross and meet	36	STEM is where subjects cross and meet through authentic activities that are grounded in real-world issues and data.
STEM as economic capital	9	STEM is important because it prepares students to become a part of the future workforce that is increasingly STEM-related.			

Stereotypes of STEM	4	STEM comes with labels or stereotypes, such as being hard and male dominated.			
RQ2: How do PSTs make sense of STEM activities in a classroom context before and after an integrated STEM unit?					
Expectations of STEM activities	26	STEM activities are seen as student-centered, inquiry-driven, hands-on, and contextually relevant ways to promote critical thinking and knowledge transfer across the subject domains. These activities have specific roles for teachers (e.g., asking questions/facilitating) and students (e.g., analyzing data).	We DO STEM activities together	47	STEM is not specific content subject-related knowledge but rather something that students' do. It is a set of collaborative practices between students and between teachers and students. These practices have required roles for teachers (e.g., circulating and probing student thinking with questions) and students (e.g., producing/gathering data).
			Data as the bridge	10	Data is the site where discipline-based content and practices can cross and meet.
RQ3: After the STEM unit, what do PSTs continue wanting to know about STEM and foresee as the challenges for implementation?					
			Planning for STEM requires the other disciplines	16	PST's identify time planning with teachers from other disciplines as a challenge to have but necessary for effective STEM implementation.
			In-the-moment challenges	24	PST's describe challenges related to pedagogy (e.g., scaffolding, facilitating classroom discussion) and content (e.g., having a deep knowledge of multiple disciplines) that can arise when planning and implementing STEM activities.

6.1. RQ1: How do PSTs make sense of STEM (in education or generally) before and after the STEM unit?

Three themes describe PSTs' prior knowledge about STEM before the STEM unit: *blurring the lines between subjects*, *STEM as economic capital*, and *stereotypes of STEM*.

In describing STEM as *blurring the lines between subjects*, PSTs demonstrated an uncertain understanding of STEM largely through a disciplinary and multidisciplinary lens. "I know that STEM stands for Science, Technology, Engineering and Mathematics. Thus, anything that has to do with STEM must fall into one of those categories," one PST explained. Another indicated, "STEM is a way of combining science, technology, engineering and math." Through statements like this, PSTs' prior knowledge of STEM showed they understood STEM as a blurring of subjects but struggled to describe the blur. However, some PSTs did move past a multidisciplinary understanding of STEM and attempted to describe the blur across subjects, "STEM is integrating science, math, technology, and engineering to teach concepts with real-world application. To me science and mathematics provide more of the conceptual aspect and engineering and technology provide the basis to complete these studies." While this and other similar responses broadened STEM past a disciplinary lens, there was ambiguity in their understanding of STEM.

Beyond levels of integration, PSTs' prior knowledge indicated *STEM as a type of economic capital* students accrue to prepare for future careers. "STEM becomes very important potentially nowadays because many occupations are related to STEM. Moreover, since the 21 century is the Era of Technology, STEM becomes big deal," one PST asserted. PSTs also considered the various stigmatizations of STEM, culminating in the theme, *stereotypes of STEM*. Here, PSTs described STEM as "being hard and not fun" or found the field of STEM as gendered because there are "a lot of men." These themes, along with *blurring the lines between subjects*, describe PSTs' initial understandings prior to the STEM unit, where they had individually made sense of STEM as an important set of skills for students to learn, but were unclear what those skills might be and how students can learn them.

After making sense of STEM together during the STEM unit, only one theme emerged to describe PSTs' situated understanding of STEM: *where subjects cross and meet*. In describing this theme, PSTs demonstrated a more nuanced and deeper understanding of STEM, indicating increased levels of STEM integration (i.e., multidisciplinary, interdisciplinary, and transdisciplinary). For instance, one PST explains the *cross* as a place situated in authentic problems and reliant on the application of discipline-based practices: "STEM includes the application of science, technology, engineering, and mathematics to solve problems or make sense of natural phenomena. It includes inquiry, evidence, argumentation, and reasoning." Another PST describes the *meet* as a place where mathematics and science practices create a STEM practice: "STEM is a practice that allows you to incorporate the different types of science and mathematics into solving problems. It's a way to apply them all together and use the skills from different parts." Together, these two responses are examples of how the group of PSTs no longer described STEM as disciplinary and began showing a more situated understanding of STEM that included higher levels of integration.

PSTs' new situated understanding of STEM was further shown in the plausible stories they told in their STEM lesson sketches. Of the twelve lesson sketches generated by the PSTs, all included some use of technology for analyzing and visualizing data (e.g., GIS, Desmos, CODAP) and five lessons were identified as multidisciplinary, four interdisciplinary, and three transdisciplinary, with zero disciplinary. Multidisciplinary lesson sketches included both science and mathematics content centered around a common theme but separated the content when describing the lesson. For example, in a lesson on modeling evolutionary change of peppered moths over time, PSTs wrote "for the science side" and "for the mathematics side" to discuss lesson objectives, processes, and outcomes, and this delineation of subjects was furthered in their description of the lesson steps. Interdisciplinary lesson sketches showed PSTs using complementary concepts and skills from mathematics and science to elaborate and explain the other, deepening the knowledge and skills being learned. For example, in a lesson about environmental impacts of landslides, PSTs described how students would "gather and interpret data in order to create graphs that show the impacts of landslides and explain those impacts on the environment." Transdisciplinary lesson sketches posed authentic problems that situated student learning through the use of knowledge and skills in math, science, and beyond. For example, in a lesson on sustainability and minimizing human impact on the environment, PSTs described how students would "create a device that will filter water the most efficiently with the least cost for filtration material," learning and applying skills across the STEM disciplines. Together, the survey and lesson sketch data indicate that, after the STEM unit, PSTs were able to develop more transformational ways of understanding STEM that more clearly defined the blur through multidisciplinary, interdisciplinary, and transdisciplinary ways.

6.2. RQ2: How do PSTs make sense of STEM activities in a classroom context before and after the STEM unit?

Only one theme emerged to describe PSTs' prior knowledge of STEM activities in the classroom before the STEM unit: *expectations of STEM activities*. Here, many of the expectations PSTs' described were broad and vague. For example, one PST said STEM activities should include, "engaging with the STEM content in a way that builds understanding." However, some PSTs described more specific roles for teachers and students in STEM activities, such as a PST who indicated that, "the teacher should be facilitating and leading the discussion while the student should be asking questions." Overall, *expectations of STEM activities* illuminated how PSTs' prior knowledge of STEM activities initially involved many buzzwords (e.g., hands-on, engaging) but they failed to unpack them in meaningful ways, demonstrating the difference between knowing about something versus knowing how to *do* something.

After the STEM unit, two themes emerged to describe PSTs' situated understanding of STEM activities: *we DO STEM activities together* and *data as the bridge*. Under *we DO STEM together*, we see PSTs beginning to describe a clearer and connected vision for STEM activities, where teachers and students engage in a set of collaborative practices with specific roles, similar to the situated and practice-oriented STEM framework of Kelley and Knowles (2016). For example, PSTs described STEM activities as where students use skills from multiple subjects to explore an authentic problem and are "communicating and collaborating in groups," linking to both the discipline-based practices and situated nature of the Kelley and Knowles' (2016) framework. Regarding the role of the teacher, PSTs described a more student-centered approach, where the teacher is a facilitator who acts as a collaborator with students and other teachers when designing and implementing STEM activities. From this theme, we see how the STEM unit pushed PSTs to develop clearer visions of STEM enactment.

The STEM unit also pushed PSTs towards a situated understanding of data's role in connecting STEM disciplines. Here, the PSTs describe *data as a bridge* between STEM disciplines STEM and to the real-world. For example, one PST described how "data should look like things that could connect to more than one content." PSTs further tease out this bridge as being rooted in the real world because the data they describe using authentic data either from the real-world or able to be collected or produced by students. The clarity of *data as a bridge* is so salient for some PSTs that they began to provide examples of real-world data students could use to create that bridge, such as, "the number of bacteria (that replicate) in a cup each minute could be used to also calculate for rate of change." Additionally, in the lesson sketches, PSTs largely used data as the catalyst to situate student learning around authentic data. For instance, one lesson involved students exploring GIS data and making recommendations regarding rising sea levels in Miami-Dade County. These PSTs showed how data served as the site for exploring a scientific phenomenon using technology literacy, mathematical thinking, and scientific inquiry, all of which are situated in the authentic practice of STEM professionals (Kelley & Knowles, 2016). Across the lessons, others also used data as the bridge to connect regression analyses with understanding scientific concepts and engineering-design (e.g., developing a water filtration system and exploring issues with coastal erosion, landslides, and population growth), further showing how their newfound situated understanding of STEM could be plausibly enacted in their future classrooms.

6.3. RQ3: After the STEM unit, what do PSTs continue wanting to know about STEM and foresee as the challenges for implementation?

After the STEM unit, two themes emerged regarding challenges and gaps in learning PSTs foresee in relation to STEM: *planning STEM requires other disciplines* and *in-the-moment challenges.* Regarding *planning STEM requires other disciplines,* PSTs discussed how communication and collaboration with teachers in other disciplines would help share the intellectual load of combining disciplines in one lesson and help navigate the challenge around STEM activities having multiple "correct answers." PSTs saw other teachers as the most fundamental resource for helping create successful STEM experiences in their classrooms, as others can provide insights and knowledge that would otherwise be lacking. However, many also expressed concerns about the time and space they would have to engage in such collaborations. While the PSTs appreciated the lesson plans given to them during the unit and the cross-over lesson sketch activity, they wondered when they might have the experience of developing STEM lesson with other teachers in the future.

Under *in-the-moment challenges*, PSTs described challenges they would anticipate when implementing a STEM activity. For instance, PSTs discussed how students may not arrive at or understand the answer the teachers intended or predicted that some students may not understand why certain functions/equations make sense for modeling natural phenomena. PSTs also described how students may or may not be familiar with the real-world context of an activity, anticipating this might hinder students' ability to make sense of the STEM activities and consider other factors that would interact with the real-world phenomena under consideration. In addition, PSTs described challenges to scaffolding STEM lessons to alleviate the burden on students' learning to use technology and worried about being able to facilitate classroom discussions about content from STEM activities that they may not be as knowledgeable about (i.e., mathematics teachers worried about facilitating discussions about and explaining science phenomena, or science teachers being worried about facilitating discussions about and explaining mathematics content) while also keeping students in on-task discussions. This theme of *in-the-moment challenges* is indicative of PSTs' careful considerations about how a STEM activity would be enacted in their future classrooms while attending to issues of both pedagogy and content.

7. Discussion

7.1. Key findings

The preceding findings highlight the shift to a collective, situated, and deeper understanding of STEM that PSTs developed after engaging in a STEM unit designed around sensemaking. Similar to the ways stakeholders and PSTs hold varying practices and views of STEM (e.g., Radloff & Guzey, 2016), we also found PSTs hold varying views. Specifically, PSTs' prior knowledge and experiences resulted in them beginning the STEM unit with individual sensemaking about STEM that indicated an understanding of STEM through stereotypes, economic capital, and as a blur between disciplines. After further making sense of STEM with other PSTs during the STEM unit, they were able to reconcile their varied views to a more nuanced and situated understanding of STEM, bringing clarity to the blur. The context and design of the STEM unit—bringing together mathematics and science PSTs, along with the activities and materials PSTs engaged with and discussed—pushed PSTs to develop a collective, situated understanding of STEM as a place where subjects cross and meet (Spillane et al., 2002). This shift in understanding allowed PST to describe a more plausible story of STEM integration at higher levels, as indicated by the largely interdisciplinary and transdisciplinary lesson sketches PSTs developed (English, 2016). Teachers' self-report data, like the survey and lesson plans collected in this study, have been shown to be a valid proxy for the actions teachers take up in the classroom (Copur-Gencturk & Thacker, 2021). Thus, we view the finding of PSTs increased levels of STEM integration in their lesson sketches as indicative of how they plan to take up higher levels of STEM integration in their future classrooms and provide their students with better opportunities to engage in authentic and high-quality STEM activities.

PSTs also showed evidence that their understanding of STEM activities shifted to a more targeted, situated vision for STEM enactment that links to the STEM discipline-based practices and data modeling framework proposed by Kelley and Knowles (2016). No longer were PSTs vaguely describing STEM activities with generic buzzwords, instead they were using very intentional and descriptive language about how teachers and students *do STEM activities together* and how these activities use *data as the bridge* between disciplines and to the real-world. The type of data PSTs discussed using was either student-collected or from the real-world and served as the catalyst for teachers and students to engage in a variety of discipline-based practices and authentic problems using student-friendly technologies. These descriptions mimicked the data collection processes and conversations around the *Chutes-R-Us* and GIS activities and lessons from the STEM unit. Though predictable, due to the STEM unit design, this shift is important because PSTs were able to select these specific elements as plausible to their future practice and develop an emerging picture of STEM that brought coherence to its ambiguity (Ancona, 2011). Furthermore, developing an understanding of STEM through discipline-based practices and data modeling aligns with current reform efforts in mathematics and science education (CCSSM, 2010; NGSS, 2013) and doing so helps PSTs make sense of STEM teaching as more practical and not much different from what they are already learning in individual mathematics and science teaching methods courses. All of which better prepares PSTs to engage in continued sensemaking around the calls for more STEM in single-discipline classrooms.

Though PSTs described STEM in more plausible and concrete ways after the STEM unit, they also anticipated many of the challenges that in-service teachers describe in relation to STEM (Margot & Kettler, 2019). For instance, we found PSTs described challenges related to planning and implementing STEM activities, where they anticipated challenges around their own knowledge about concepts and finding time to plan with teachers in relation to other disciplines. The PSTs also forecasted challenges with students' ability to effectively navigate available technologies and make connections between scientific phenomena and mathematics. These concerns are common among in-service teachers but demonstrated how PSTs were thinking critically and transferring their learning about STEM to their future teaching contexts. Moreover, this anticipation of STEM-related challenges lays the groundwork for continued sense-making around the varied requirements and expectations of their future careers (Weick et al., 2005).

Overall, we saw how mathematics and science PSTs engaged in sensemaking together, during a STEM unit, situated their understanding of STEM and further clarified their vision for specific actions they would need to take to make STEM a reality. We credit this shift in understanding to the STEM unit design where they engaged in an engineering design task, explored student- and discipline-friendly technologies, and developed lesson sketches, while engaging in discourse around implications for content and practice (Cohen & Hill, 2001; Allen & Penuel, 2015). We also believe this study serves as an important model for teacher education programs to consider using when preparing single-discipline teachers to meet the call for STEM. Considering many mathematics and science PSTs are not exposed to specific STEM teaching methods in single-discipline methods courses, this study highlights the need for teacher education programs to manage the dilemma around what type of exposure to STEM teaching benefits PSTs while also considering the discipline-specific goals of the course. We argue that STEM is better navigated mathematics and science PSTs together, because together they can help each other make sense of and identify specific plausible elements of STEM which serve as bridges for their continued sense-making and future enactment in classrooms.

7.2. Implications

Stepping back, we discuss three implications for mathematics and science teacher education that align with our purpose of exploring PSTs' understanding of STEM and supporting teacher sensemaking about STEM.

Provide opportunities for PSTs to plan together. One of the most concrete barriers facing in-service teachers regarding STEM is their own content knowledge and capacity to plan STEM activities (Margot & Kettler, 2019). We recommend that teacher educators provide opportunities for PSTs from different disciplines to plan for STEM together. As seen in this study, even planning one lesson together provided PSTs with a model of how this type of collaboration should work and exposed them to different teaching-related concepts, technologies, and practices which deepened their understanding of STEM enactment.

Use authentic data as the site for connecting STEM disciplines. Collecting, modeling, and analyzing data is a core feature of both mathematics and science standards (CCSSM, 2010; NGSS, 2013), which makes it vitally important for PSTs to make sense of this practice prior to entering the field. Data is also a rich context for STEM learning (Lehrer & Schauble, 2020) and flexible enough to engage students in cross-disciplinary practices that help students make sense of the real-world. We recommend, as seen in this study, STEM activities that center real-world data and use student-friendly data analysis technologies as a means to support teacher sensemaking about STEM integration.

Focus PSTs' STEM learning through sensemaking. Similar to others (Allen & Penuel, 2016; Cohen & Hill, 2001; Davis et al., 2020), we also recommend teachers engage in recurrent professional learning, that focuses on content and different dimensions of practice, as an effective framework to support sensemaking. This can be done with PSTs by engaging in more open-ended and cognitively demanding tasks that link these experiences to their future jobs as teachers. Key here is understanding teaching methods and assistive technologies that support and facilitate the enactment of STEM activities, and modeling and engaging PSTs in these ideas will go a long way in supporting their future implementation.

7.3. Limitations and recommendations for future research

We used two STEM frameworks to design our STEM units, and although we emphasized discipline-based practices, data modeling, and student-friendly technologies as a context for PST learning about STEM, one can easily imagine other contexts for STEM learning. For instance, learning events designed around computational thinking (e.g., Weintrop et al., 2016), robotics (e.g., Kim et al., 2015), or even STEAM (STEM with Arts) practices that go beyond disciplinary boundaries and begins to take a more transdisciplinary approach to STEAM teaching and learning (Mejias et al., 2021). While we take the view that our approach is both a core and accessible focus for STEM learning, we also recognize that other approaches may have different outcomes for PSTs and believe the topic of what knowledge and practices single-discipline PST learning about STEM should focus on is generative for future research.

We also worked with a small number of PSTs at a single university and used surveys without individually identifiable information, focusing our analysis on the collective. Though we saw sufficient variability among the PSTs, this small and situated sample means that some of our findings may be highly particular to our own teacher preparation context. Future work may explore similar STEM activities in different contexts to better understand which parts may generally support PSTs developing productive views of STEM and which were due to the particularities of our setting. Additionally, future studies may narrow the unit of analysis to the individual PST to gain more nuanced insights about teacher change at the individual level, as this study did not link pre-to-post surveys and focused more on the collective shift in PSTs' understanding of STEM.

8. Conclusion

Sensemaking is inherently collaborative and serves as an opportunity for learners to develop coherence about a topic and actionable steps. While STEM can be challenging for teachers and PSTs working in individual disciplines, this study is an example of how teachers can learn better together, drawing on each other's discipline-based knowledge and practices. Further, focusing STEM learning through discipline-based practices, data, and appropriate technologies served as a fruitful approach for deepening PSTs' understanding of STEM. Doing these can help make STEM a more practical reality in mathematics, science, and perhaps STEM classrooms.

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