Eliciting and Refining Conceptions of STEM Education: A Series of Activities for Professional Development

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Abstract

Integrated STEM (science, technology, engineering, and mathematics) education is becoming increasingly common in K–12 classrooms. However, various definitions of STEM education exist that make it challenging for teachers to know what to implement and how to do so in their classrooms. In this article, we describe a series of activities used in a week-long professional development workshop designed to elicit K–12 teachers' conceptions of STEM and the roles that science, technology, engineering, and mathematics play in STEM education. These activities not only engage teachers in conversations with peers and colleagues in a professional development setting but also enable teachers to reflect on their learning related to STEM education in the context of creating lesson plans and considering future teaching. In addition to describing these activities, we share suggestions related to how these activities may be used in venues outside of professional development.

Introduction

Current policy documents have called for K–12 science classrooms to employ integrated science, technology, engineering, and mathematics (STEM) strategies that provide a more authentic learning environment for students (Honey et al., 2014). Although the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) and state standards that include engineering (Moore et al., 2013) strongly support the incorporation of engineering into science classrooms, the nature of engineering and how to effectively integrate it into science teaching is typically outside of most teachers' knowledge bases (Cunningham & Carlsen, 2014). Although national policy documents strongly support the integration of STEM education, there remains disagreement on models and effective approaches for integrated STEM instruction (e.g., Breiner et al., 2012; Moore et al., 2020; Martín-Páez et al., 2019).

Because of this disagreement, there is a need to better understand what integrated STEM education is in order to implement it in practice. The literature reveals a wide variety of approaches that include: STEM as a replacement term for science and mathematics (Breiner et al., 2012; Sanders, 2009), STEM as a pedagogical shift toward an integrated approach (Breiner et al., 2012; English, 2016; Honey et al., 2014; Kelley & Knowles, 2016), curriculum changes that reflect the work of STEM professionals (Breiner et al., 2012; Labov et al., 2010; Sanders, 2009), and curricula that emphasize engineering design challenges (Bryan et al., 2015). Despite these variations in definitions, there are common elements across these approaches to STEM, such as the inclusion of an engaging, real-world context (e.g., Breiner et al., 2012; Brown et al., 2011; Moore et al., 2020); explicit connections between science, technology, engineering, and mathematics and modeling those connections as they would be observed in STEM careers (e.g., English, 2016; Herschbach, 2011; Honey et al., 2014; Kelley & Knowles, 2016; Moore et al., 2020); the intentional development of 21st-century competencies (e.g., Bryan et al., 2015; Honey et al., 2014); and an emphasis on student-centered pedagogies (e.g., Bryan et al., 2015; Breiner et al., 2012; Labov et al., 2010; Sanders, 2009). In short, integrated STEM education is a complex combination of content and pedagogy, which makes it difficult to define.

This creates an additional challenge for teachers who are asked to implement integrated STEM. Professional development (PD) is one way to assist teachers not only in learning integrated STEM education instructional practices but also in helping them conceptualize what integrated STEM education means within their particular context. This is especially important given that “PD programs have the best chance of impact on teacher and student outcomes when the goals of the PD program are aligned with policies at the school, district, and state levels, as well as existing teacher beliefs regarding STEM” (Johnson & Sondergeld, 2015, p. 204). By eliciting teachers’ conceptions of integrated STEM education at the beginning of a STEM-focused PD through drawing conceptual models, facilitators can help teachers move from undefined or vague models to better defined models (Dare et al., 2019; Ring et al., 2017); similar activities have been included in preservice teacher education (Radloff & Guzey, 2016). Furthermore, teachers can reference these drawings during the PD to help them conceptualize integrated STEM curricula and recognize when their conceptual model has changed.

In our previous work analyzing teacher’s conceptual models of STEM, we found that K–12 science teachers’ understanding of what STEM education is varied greatly (Ring et al., 2017). These models ranged from simply using STEM as an acronym to prioritizing science or engineering to focusing on real-world problem-solving. We found that teachers’ conceptions reflected the variety of definitions that exist in the literature (e.g., Bybee, 2013) and that these conceptions can change through PD, curriculum writing, and implementation. Our prior research allowed us to meaningfully redesign previously used activities and design new activities for use in PD settings that would allow teachers to confront their conceptions of integrated STEM education, reflect on those conceptions, and collaborate with others to better define what STEM education is in their specific teaching context.

The work presented here highlights activities designed to elicit STEM conceptions during a week-long PD workshop on integrated STEM education. Informed by our prior work, the purpose of these activities was to elicit teachers' conceptions of integrated STEM, share and reflect on those conceptions with others, use those conceptions as a foundation to guide the writing of curricular materials for classroom use, and ultimately develop new conceptions of STEM education through reflection. These activities may be used in a variety of settings, and we offer suggestions for alternative implementation.

Professional Development Context

The work described here is part of a larger 4-year funded project that seeks to improve the quality of K–12 integrated STEM education in science and engineering classrooms through the development and dissemination of a classroom observation protocol for integrated STEM instruction. The authors are two of the five principal investigators (PIs) on the project. As part of the project, three separate week-long (5-day) PD workshops were offered near the home institutions of project personnel, which include a large Southeastern city (Site 1) and a large Midwestern city (Site 2). One secondary (middle and high school) PD workshop was offered at Site 1, and two separate PD workshops were offered at Site 2: one elementary (K–5) and one secondary (high school). The professional development activities were planned jointly by project personnel from both sites, allowing for site-specific modifications as necessary. The project PIs designed and facilitated the PD with the assistance of several graduate research assistants and science and STEM coordinators from the local school and district. Within the context of the larger project, these workshops provided teachers with a foundational knowledge of integrated STEM; examples of integrated STEM activities, lessons, and units; and dedicated time to develop their own curriculum materials for classroom use. The teachers in these workshops were then expected to participate in classroom observations when they implemented their developed lessons (typically one or two 50-minute class periods) or curricular units (anywhere from week-long units to units that spanned several weeks) the following school year. The observations also allowed project personnel to continue supporting teachers' learning and implementation of integrated STEM education because observations were followed by post-observation coaching conversations.

Participants. A total of 106 participants across the two sites participated in the three PD workshops (Table 1). Of these participants, 21 teachers participated in the secondary PD at Site 1; 58 teachers, two principals, and five instructional coaches participated in the elementary PD at Site 2; and 15 teachers, two administrators, and three instructional coaches participated in the secondary PD at Site 2. These teachers came from six different school districts. Two of these were large urban school districts, three were large suburban districts, and one was a smaller, rural district. The secondary teachers taught across multiple content areas: There were 12 middle school science teachers, eight biology/life science teachers, seven chemistry teachers, four physical science or physics teachers, one environmental science teacher, one photography teacher, one agriculture teacher, and one orchestra teacher.

Table 1

Professional Development Participants

	SITE 1	SITE 2: Elementary	SITE 2: Secondary	Total
Participants	21 Teachers	58 teachers 2 principals 5 instructional coaches	15 teachers 2 principals 3 instructional coaches	106
Districts Represented	Large, Urban	Large, Urban Large, Suburban Small, Rural	Large, Urban Large, Suburban (2) Small, Rural	8
Content Areas Represented	PS/Physics (7) Chemistry (3) MS Science (6) LS/Biology (5)	Elementary	PS/Physics (4) Chemistry (3) LS/Biology (2) MS Science (2) Earth Science (1) Agriculture (1) Photography (1) Orchestra (1)	9

Our integrated STEM education framework. During the PD, we elicited teachers' conceptions of integrated STEM education, exposed teachers to different approaches to integrated STEM instruction, actively engaged these teachers in example integrated STEM activities, and supported teachers in developing integrated STEM curricular materials for use in their classrooms. The definition of integrated STEM education that guided our work was adopted from Kelley and Knowles (2016) who defined integrated STEM education as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p. 3). This definition was selected due to its emphasis on student learning through context and making connections between disciplines and its flexibility as to how many domains were needed to "count" as integrated STEM. To reflect the states' science standards and district initiatives, activities in the PD fore-fronted science and engineering, but mathematics and technology were integrated into the activities throughout the week.

In addition to the broad definition of STEM education shared above, we used a project-developed integrated STEM framework to guide the workshops' activities. This framework consists of 13 components (Table 2) identified in the literature as being important within effective integrated STEM instruction (e.g., Breiner et al., 2012; Bryan et al., 2015; Martín-Páez et al., 2019; Moore et al., 2020). These components have guided the development of the larger project's observational protocol, which was still under development during the time of the PD. These components were grouped into three separate categories: STEM Concepts and Practices, STEM Pedagogies, and Contextualizing Learning. The concepts of “communicating understanding” and “collaboration” were identified as components that cut across the other three categories. Each of these 13 components was explicitly explored before, during, or immediately following at least one example of the integrated STEM activities in the PD, which is described below.

Table 2

Components of Integrated STEM Education Used in Professional Development

	Component	Brief Description
STEM Concepts and Practices	STEM Practices	Practices used by STEM professionals, including those outlined in the NGSS Science and Engineering Practices (NGSS Lead States, 2013).
	STEM-Specific Technologies	Technologies that are analogous to those used by STEM professionals.
	Multiple Solutions	Real-world problems can be solved through multiple different solutions, not just one.
	Evidence-Based Reasoning	Decisions related to science and engineering should be grounded in evidence in order to justify those decisions.
	STEM Content Integration	Content from one or more STEM disciplines is included and connections are made between the disciplines.
STEM Pedagogies	Questioning Strategies	Questions should elicit students' thinking and allow the teacher to formatively assess students throughout the lesson.
	Feedback	Constructive feedback should be shared with students as part of monitoring their overall progress.
	Connections to Prior Lessons	Concepts and/or content from previous STEM lessons are incorporated and meaningfully integrated into the lesson to help students build upon their current understanding.
Contextualizing Learning	Real-World Problems	Learning is contextualized by a real-world problem to give meaning.
	Lived Experiences	Learning is grounded within students' own lives and "outside of school" experiences.
	STEM Careers	Learning is connected to STEM careers to create student awareness.
Cross-Cutting Components of STEM	Communicating Understanding	Students have opportunities to communicate their understanding of the lesson content.
	Collaboration	Students collaborate with others to complete learning activities.

Professional development design. The overall design of the PD utilized best practices to actively engage teachers in hands-on integrated STEM instruction as learners, reflect on their learning individually and with others, try out new practices through curriculum work while receiving feedback from peers and facilitators, receive feedback on their teaching, and reflect on their teaching (e.g., Banilower et al., 2007; Capps et al., 2012; Garet et al., 2001; Luft et al., 2020; Supovitz & Turner, 2000); the last of these two practices were incorporated into the coaching support during the school year. The purpose of the PD was not to improve content knowledge but to develop teachers’ understanding of STEM education as a pedagogy, which requires developing a conceptual understanding of integrated STEM as a whole. The collaboration with the teachers’ schools and districts ensured that our PD met their needs (Garet et al., 2001; Johnson & Sondergeld, 2015; Luft et al., 2020). Teachers were asked to come to the PD with curricular materials that they currently used in their classrooms. During the PD, we engaged teachers in modifying those curricular materials to transition them from a science-only focus to one that reflected integrated STEM. Teachers used project-supplied composition notebooks to respond to key reflective prompts throughout the week, which included explicit reflections on STEM conceptions, and to keep track of their own curricular ideas.

Conceptualizing Integrated STEM Education in Professional Development

As with most PD workshops, teachers were first introduced to the logistics of the week and what the following school year would look like in relation to the larger project (e.g., continued support through observations and coaching). Before introducing teachers to our STEM framework and a mix of facilitator-designed and published integrated STEM activities, we elicited teachers' conceptions of STEM education through a series of activities and discussions. The sections that follow detail the activities used, which were revisited throughout the week as a means to reflect upon and revise teachers' thinking related to STEM. These activities provided a foundation for teachers' learning throughout the week. Although examples of integrated STEM activities are provided, the purpose of this manuscript is to share activities related to eliciting teachers' STEM conceptions and to describe how teachers used these conceptions during reflection and curriculum-writing portions of the PD.

Initial STEM conceptions drawings. At the beginning of Day 1, we tasked teachers with creating individual, sketched representations of what integrated STEM education was to them. Our previous work has shown that teachers enter into professional development spaces with their own conceptions of STEM education (Ring et al., 2017). Since the intention of this activity was to elicit each teacher's conception, we did not provide a definition or give any instruction prior to this exercise. After teachers drew their conceptions, they shared them with their self-selected table teams (approximately four or five members). As they shared, we asked teachers to identify similarities and differences among the various drawings they examined that were then shared in whole-group discussion. This exercise served to demonstrate the variety of conceptions that existed. Following this activity, the teachers responded to two prompts on the backside of their drawing: (1) "How does your STEM model compare to the other models at your table," and (2) "after seeing other models, would you make any changes to yours?" Once teachers had individually responded to these prompts, they were asked to keep their drawings out for reference during the next activity.

STEM poster activity. After sharing their conceptions about integrated STEM, each teacher was provided with four sticky notes. We asked teachers to write down their ideas related to the roles of science, technology, engineering, and mathematics in STEM education, each on a separate sticky note. Those who wanted to add more than one idea for each area used additional sticky notes. Teachers then added their sticky notes to large poster papers corresponding to each area (science, technology, engineering, or mathematics) hanging around the room. We placed the teachers in four teams, and each team was assigned to one of the large poster papers. Because of the large size of the elementary group at Site 2, there were multiple sets of posters to keep the teams small. At their assigned posters, each team read the sticky notes and then arranged them into team-developed categories that were labeled with marker.

Once each team had created and labeled their categories, teams rotated from poster to poster. While reading through the other posters, we asked teachers to reflect upon what they noticed about the identified categories, note any changes they would make to those categories, and identify how the categories across the posters related to one another, if at all. Once all teams had read through the other three posters, we facilitated a large group discussion in which the teachers shared their reflections, specifically focusing on the relationships across the posters. Teachers were then asked to individually reflect upon what it means to integrate science, technology, engineering, and mathematics using their personal conceptual models from the preceding activity by responding to the following prompt: "Using your model, explain what it means to integrate S-T-E and M." Finally, the teachers shared their ideas about the integration of S-T-E and M with their small groups, and commonalities among ideas were recorded as a whole group. The large S-T-E-M posters remained in the workshop space for the remainder of the week, and after copies were made, the teachers held on to their individual conceptions of STEM education models, which were used throughout the rest of the week as described below.

Approach to integrated STEM activities. Each day of the PD focused on one or more of the 13 components of our integrated STEM framework that were highlighted in that day's activities (an example from Site 1 in shown in Table 3). Because of the complexity of STEM education, it was important to slowly introduce these components within the context of example activities. Teachers engaged in a variety of examples of integrated STEM activities as learners followed by discussions about how to implement them into their own classrooms. Many of these activities were developed by project personnel, but some were adopted from published curricula. Appropriate state standards were shared to demonstrate alignment with curricular expectations. For each activity that was introduced, teachers first participated in the activity as students would. This allowed the teachers to encounter the same challenges that their own students might face in the classroom. Afterward, project personnel facilitated whole-group and small-group discussions to allow teachers to reflect both as learners and as educators. Each of the activities included built-in reflection time around the components emphasized during that activity, and each day concluded with a final, deeper reflection related to the days' focal components of STEM. These reflections were completed individually and collaboratively and were recorded in the teachers' STEM notebooks to document their growing conceptions of integrated STEM. As part of this, teachers spent time modifying their curriculum materials to reflect what they learned about integrated STEM education throughout the day. Teachers were encouraged to work with others who were focusing on similar science content and discuss ideas with workshop facilitators. The facilitators would frequently prompt teachers to refer back to their conception of STEM drawing as a formative self-assessment of their learning.

Table 3

Example Workshop Schedule From Site 1

Day 1	Day 2	Day 3	Day 4	Day 5
Collaboration	Real-world Problems STEM-specific technologies Communicating Understanding	STEM content integration Multiple Solutions Evidence-based reasoning Questioning Strategies	Connections to Prior Lessons STEM careers STEM practices Feedback Lived Experiences	All
Morning Activities	*Morning Activities*	*Morning Activities*	*Morning Activities*	*Morning Activities*
• Welcome and Project Introductions • Getting to Know You: Cup Challenge • PD and Project Logistics (e.g., research, content focus, expectations) • What is STEM?; Conceptions of STEM; the role of S, T, E, and M in STEM • Goal setting for the week	• Intro to Engineering • Real-world contexts in teaching • Tabletop Hovercraft • Data analysis in real time • The T in STEM • Introduction to Sphero Mini	• Heat Transfer Introduction • Storyboarding as assessment • Heat transfer inquiry lab • Introduction to engineering (engineering EDP) and Save the Penguins • Problem scoping • Materials testing	• Save the Penguins redesign • Creating multiple solutions • The importance of feedback for redesign • Careers in STEM	• Lesson development in small groups • Individual work time
Afternoon Activities	*Afternoon Activities*	*Afternoon Activities*	*Afternoon Activities*	*Afternoon Activities*
• Marshmallow Challenge • Critique and Defend • Teamwork in the Classroom • Video analysis of teamwork • Developing Team Norms • Curriculum Analysis • End of day reflective discussion	• The Client Letter • Bench Clean-Up • Curriculum Analysis • End of day reflective discussion	• Design, build, test • Evidence-based reasoning • "Gearing up" for higher grade levels • Curriculum Analysis • End of day reflective discussion	• Curriculum Analysis • Lesson development • End of day reflective discussion	• Museum walk/share lesson plans for peer review • Logistics for implementing and sharing resources • Revisiting Conceptions of STEM • Revisit goals • All PD Reflection (Exit Ticket)

For example, after the STEM conceptions activities on Day 1, we introduced teachers to our project's STEM framework and focused on one component: collaboration. To do this, we used the marshmallow challenge, a popular activity used to emphasize the importance of planning and communicating with peers (Wujec, 2010). After doing the activity as students would and discussing why collaboration was important in this activity, teachers were asked to use their STEM conceptions drawings to decide if this was an integrated STEM activity and, if not, how they might make it one. Teachers were quick to point out that the activity does not explicitly call for the inclusion of science content. They argued the value of an activity like this to engage students in collaboration and problem-solving skills, which could be the basis for introducing engineering. Even without a clear "right answer" of what STEM education is, teachers were able to think critically about what they valued. To this end, teachers reflected on whether or not their initial STEM models were robust enough to determine the difference between a STEM activity that helps students learn STEM content and one meant to develop STEM skills and practices. To end the day, we asked teachers to examine their curricular materials and reflect on where they would include collaboration. As facilitators, we checked in with teachers as they worked and encouraged them to reflect upon the presence of collaboration in their STEM conceptions drawings, modifying them as needed, and then use those drawings to guide their curriculum writing. Although collaboration had been included in some teachers' initial models, this focus on collaboration prompted others to consider this as a new addition to their model.

This pattern of being introduced to target components of STEM education each day, participating in an example STEM activity, reflecting on that activity, and working on curriculum was repeated on Days 2–4. Day 2 emphasized the importance of real-world problems, STEM-specific technologies, and communicating understanding within the context of integrated STEM activities. As part of this, engineering and the engineering design process were introduced to teachers through an introductory engineering activity (e.g., creating tabletop hovercrafts in the Site 1 PD and reviewing Engineering is Elementary in the Site 2 elementary PD). As on Day 1, the last activity of the day included reflection on the key components and a review of their Day 1 STEM conceptions, modifying them as needed, to work on their curriculum materials.

By Day 3, we had provided the teachers with foundational knowledge of integrated STEM education, arming them with the tools needed to participate in a fully integrated STEM curriculum unit. We used the *Save the Penguins* curriculum (Schnittka, 2009) to engage teachers in examining the relationship between heat transfer and the engineering design challenge of creating a well-insulated habitat for penguins. This curriculum unit allowed us to emphasize the following components of our integrated STEM framework.

- *Real-world problems*: The design challenge was framed broadly by global climate change.
- *STEM content integration*: After first learning about the three forms of heat transfer through a series of hands-on, inquiry-based activities, teachers were tasked with using their knowledge of heat transfer to complete the design challenge.
- *Multiple solutions*: Teachers worked in small groups to develop prototypes, build and test those prototypes, and then modify their designs to rebuild and retest their prototypes.
- *Evidence-based reasoning*: Teachers were tasked with explaining their design solutions using evidence collected through a variety of hands-on activities.

At the end of the activity, we facilitated discussions about these components in connection to *Save the Penguins* as well as how these elements might be highlighted in (or added to) activities the teachers already use in their classrooms; teachers also made suggestions about alternative contexts that their students might find more relatable than penguins, such as making insulated dog houses. Once more, teachers were asked to consider how this activity compared to their own developing conceptions, modify their conceptions as needed, and work on their selected curriculum materials.

Day 4 started with revisiting the importance of multiple solutions and emphasizing the importance of allowing students to learn from their first designs. We also spent time reflecting on all of the activities from the week and how they could each be presented in ways that developed students’ interest in STEM careers. The afternoon was spent entirely on curriculum development. Because the teachers had been introduced to all 13 components of the integrated STEM framework, they were tasked with incorporating these into their curricular materials, using their modified conceptions and written reflections to guide their work. Many teachers chose to work with peers, even though they were not working on the same materials.

To end the week, Day 5 was spent primarily in unstructured curriculum work time during which teachers worked with each other and the workshop facilitators to continue modifying their curricular materials. We reminded teachers of the 13 components of STEM used during the workshop and encouraged them to use their STEM conceptions, written reflections, and the posters that still hung on the walls as they worked. After sharing the progress on the curricular materials and reviewing logistics for the coming year (including how to share curricular materials within the group), we ended the PD by repeating the STEM conceptions activity.

Revisiting the STEM conceptions activity. In the afternoon of Day 5, we asked teachers to examine their conceptual models and written reflections from Day 1 before drawing a new model of STEM education. We reminded teachers that (just as before) there were no wrong answers. If they felt that their model had not changed, they were not obligated to change it; however, they were required to draw it on a new sheet of paper. Similar to the Day 1 activity, teachers shared their new models with their tablemates and identified similarities and differences across the different models present at their tables. Additionally, we asked the teachers to compare their own two models. We specifically asked them to consider how their own models had changed (if at all) and how they planned to implement their model during the upcoming school year. We asked them to write their responses to the following questions on the back of their second model.

1. "How does your STEM model from today compare to your previous model?"
2. "Describe how your STEM thinking has both changed and stayed the same. What do you think or know that is new?"
3. "What will be your approach to implementing this model into your classroom?"

Although these written reflections were done individually, teachers also shared their reflections with their peers during a whole-group discussion. These final models were collected and copied by facilitators.

Outcomes of STEM Conceptions Activities

Unsurprisingly, we observed that participating teachers came to the PD with different ideas related to what STEM education is. Because of this, teachers were able to engage in meaningful discussions with their peers to consider multiple perspectives. For instance, some teachers focused on the presence of multidisciplinary content, some focused on the engineering design process, and others focused on framing STEM as real-world problem-solving. These different models showcased how STEM was conceptualized by teachers as a mix of content and pedagogical considerations. The reflections that arose out of conversations with peers allowed teachers to identify similarities and differences across their conceptions of STEM, positioning them to understand that STEM does not have to be just one thing. Furthermore, they recognized that there were common features valued across the models and that no model was "wrong." In reviewing the Day 1 reflections, we found that 75% of the 106 teachers noted that they would want to make changes after seeing other models, stressing the importance of multiple "correct" models. This supports the rest of the work during the week in which teachers engaged in activities that encouraged them to revise their thinking. The workshop activities emphasized the constant revision of thinking surrounding STEM education because each activity focused on different components of STEM education from our STEM education framework. At no point did we, as facilitators, suggest that there was one way to "do STEM." By pointing to their Day 1 models throughout the week, we encouraged teachers to consider whether or not their model was still an accurate representation of their understanding of STEM education and to refine their thinking in the process.

The repeated STEM conceptions activity on Day 5 allowed teachers to consider their learning over the course of the week and think forward to the upcoming school year. Some teachers chose not to modify their drawings, but side-by-side comparisons revealed that 91% of the teachers made changes, many of which included the addition of pedagogical elements from the PD activities. For example, one high school teacher's drawing changed from a complex model that focused on content to a simple model of STEM education that showcased STEM education as a strategy (Figure 1). One elementary teacher shifted from thinking STEM was equivalent to a linear engineering design process to recognizing that STEM includes real-world problems, collaboration, and multiple solutions (Figure 2). Through these side-by-side comparisons, it is clear that most teachers' conceptions changed. Furthermore, the inclusion of some of the 13 components of our STEM framework in teachers' models on Day 5 indicates that teachers saw value in the framework we shared. Because our own STEM framework shared with teachers was not prescriptive, teachers were able to highlight which components were of importance to them in their models.

Figure 1

Day 1 and Day 5 conceptions of STEM education from a high school teacher.

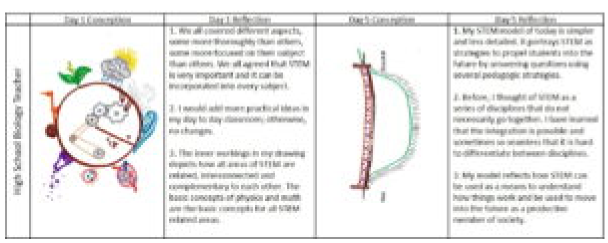
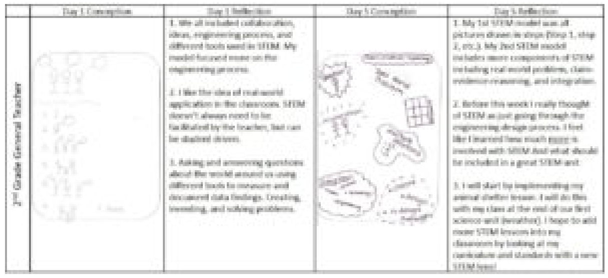


Figure 2

Day 1 and Day 5 conceptions of STEM education from an elementary teacher.



	Day 1 Conception	Day 1 Reflection	Day 5 Conception	Day 5 Reflection
2nd Grade General Teacher		1. We all included collaboration, ideas, engineering process, and different tools used in STEM. My model focused more on the engineering process. 2. I like the idea of real-world application in the classroom. STEM doesn't always need to be facilitated by the teacher, but can be student driven. 3. Asking and answering questions about the world around us using different tools to measure and document data findings. Creating, inventing, and solving problems.		1. My 1st STEM model was all pictures drawn in steps (Step 1, step 2, etc.). My 2nd STEM model includes more components of STEM including real world problems, claim-evidence-reasoning, and integration. 2. Before this week I really thought of STEM as just going through the engineering design process. I feel like I learned how much more is involved with STEM and what should be included in a great STEM unit. 3. I will start by implementing my animal shelter lesson. I will do this with my class at the end of our first science unit (weather). I hope to add more STEM lessons into my classroom by looking at my curriculum and standards with a new STEM lens!

Although the first STEM conceptions activity is a modification of an activity that we had previously used in workshops, the “Roles of S-T-E-M” large poster activity was new (Figures 3, 4, 5, and 6). We designed this activity based on our experience in observing how science, technology, engineering, and mathematics are used in lessons tagged as integrated STEM such that often S, T, E, and M are present but not necessarily well-defined or explicitly connected to one another (Dare et al., 2019; Ring-Whalen et al., 2018). The third reflective prompt on Day 1 (“Using your model, explain what it means to integrate S-T-E and M”) aimed to help teachers consider how these roles might play out in their own models. By allowing teachers to first consider the various roles and purposes of science, technology, engineering, and mathematics, they were better prepared to consider how these disciplines might work together when considering an integrated STEM approach in their models. For instance, the Site 1 secondary science teachers conceptualized science in STEM education as the intersection of theory and practice that leads to innovation (Figure 3). They also positioned technology in STEM education as assisting with teaching strategies that provide students with hands-on applications to collect data and communicate. This activity explicitly asked teachers about the connections between S, T, E, and M, which is often not captured in drawn models alone (Dare et al., 2019) but is important when considering lesson planning and implementation.

Figure 3

Role of science in STEM poster by the secondary science teachers at Site 1.

Figure 4

Role of technology in STEM poster by the secondary science teachers at Site 1.

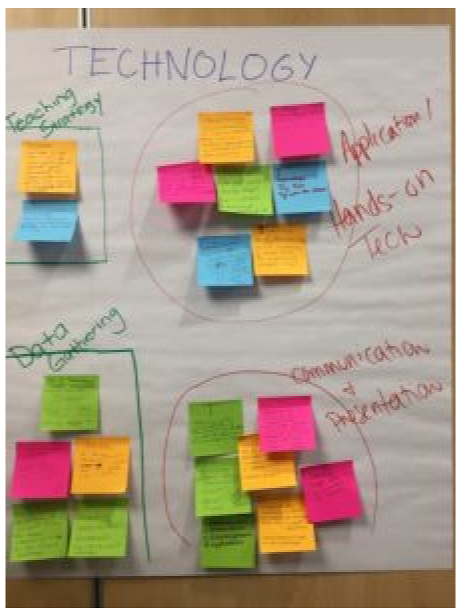


Figure 5

Role of engineering in STEM poster by the secondary science teachers at Site 1.

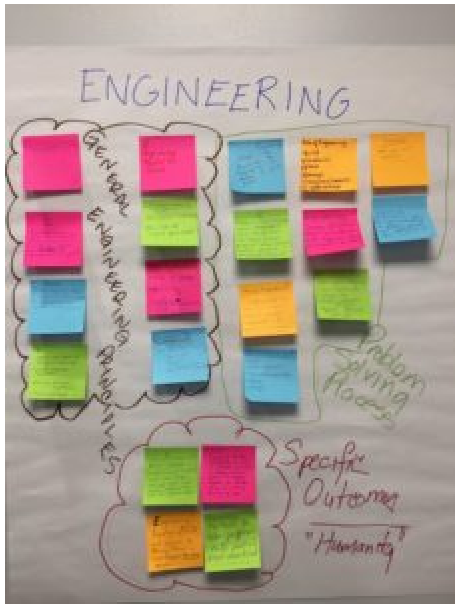
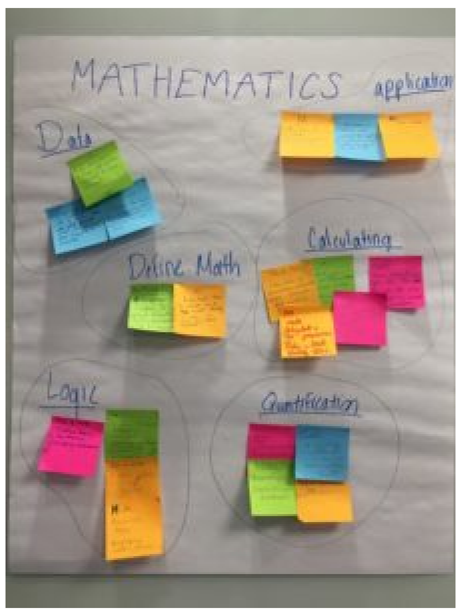


Figure 6

Role of mathematics in STEM poster by the secondary science teachers at Site 1.



Facilitator Reflection on Activities

As facilitators, this set of activities allowed us to activate the different conceptions of STEM education teachers held before they engaged in STEM activities when they might assume there is one way to "do STEM." Additionally, they allowed teachers to work with others to understand that STEM education is not just one prescribed way of teaching that has to be conducted in the same manner all the time. Through activities designed to elicit STEM conceptions, teachers engaged in rich conversations that allowed them to explore a variety of conceptions of STEM, thus, leading to a deeper understanding of what STEM can look like in different contexts. These conversations and explicit reflections on the integrated

STEM activities helped the teachers further develop their own conceptions of STEM, as indicated by the changes from Day 1 to Day 5. We were able to help the teachers actualize and refine their conceptions of STEM as we guided the them in curriculum writing throughout each day of the PD.

Furthermore, these activities allowed teachers to confront what roles science, technology, engineering, and mathematics play in STEM education in their own classrooms. Our previous work noted that teachers' interpretations of models of STEM failed to show how to "do STEM" (Dare et al., 2019), so these activities required teachers to specifically consider the mechanisms through which they might integrate across various content areas. This helped the teachers identify places where science, technology, engineering, and mathematics can be integrated more naturally, which resulted in conversations about what, specifically, that integration can look like. These conversations were important in helping the teachers develop curricula for their own classrooms that not only included two or more of the STEM disciplines but also included various elements addressed in the PD, such as collaboration and solving real-world problems.

Implementing these activities was not without challenges. Some teachers began the week looking for the "correct" way to "do STEM" and were initially disappointed that they would not be provided one answer, nor would they be blindly led through examples of integrated STEM curricula. Our approach required teachers to consider their own ideas and reflect on their learning. Additionally, the conceptions elicitation activities were inherently challenging and cognitively demanding tasks because they forced individuals to interrogate something that they were not necessarily confident about. Reminding the teachers that there was no wrong answer was key in eliminating some of their fears associated with being wrong; these fears were further ameliorated by sharing ideas in small groups first before opening up to the large group. Our openness to discussion, constant challenging of ideas, and adoption of high-quality PD practices (e.g., peer collaboration, engaging in activities as students, and dedicated curricular work time) allowed us to push teachers to question others and reflect on their own learning, which proved successful.

Teacher feedback solicited on the last day demonstrated that the overall design of the PD was well-received. Although differences existed across the three workshops, the positive feedback was echoed. For instance, one secondary science teacher from Site 1 shared:

> The theory combined with the modeling followed by action and reflection made the PD very effective. I feel very confident in my ability to integrate STEM in my classroom because of the format in which this PD was presented. I also loved the time that we had to develop units and lessons that integrate STEM.

Site 2 was no different. The positive feedback from secondary and elementary teachers at Site 2 was very similar. One secondary science teacher shared the following:

> Thank you for a great week of learning. I was very happy with the workshop and what I learned. Thank you for the time to work on lessons/units that are applicable to what we will do. The time to chat with others helped A LOT!

Elementary teachers at Site 2 also valued their new knowledge:

> The time to collaborate and discuss our learning with colleagues was incredibly helpful. It allowed us to take the new information and apply it to our individual units, schools, etc. It also allowed us to digest the information and ask questions in a safe environment.

From these examples, it is clear that the ability to directly have a take-away product that teachers could immediately use in their classrooms and the conversations with others was beneficial.

Furthermore, these types of activities allowed us to address these very visual conceptions in the moment and to refer back to them throughout the PD to reflect on and refine their understanding of STEM. As they participated in the workshop activities, teachers often referenced the large poster papers that hung in the room as a reminder of different ways to incorporate each of the STEM disciplines while they worked on developing their own lesson plans. Additionally, when teachers requested assistance during curriculum writing, we frequently asked them to revisit their conceptions and consider if they needed modification or how they were being actualized in their planning. Full curriculum materials and observations are still being collected as part of the larger project; however, we anticipate that this may result in more cohesive and more well-integrated lessons and units. Future research will address how teachers' conceptions of STEM were actualized in their curricular materials and implementation.

Implications for Future Practice

These activities were used primarily with inservice teachers, but they can also be used with administrators, preservice teachers, and teacher educators to better parse out what STEM education means and how to enact it. In schools and districts moving to become STEM schools or STEM districts, these activities could be used to develop a unified vision for STEM within the school or district, which is important for making forward progress. Participating administrators then have an opportunity to gain a realistic sense of what is being asked of their teachers when tasked with developing integrated STEM lessons and implementing them in the classroom. The conversations these activities promote are useful in helping to define STEM education within bounded contexts.

These activities can also be used for research, the primary motivation in the initial creation of the STEM conceptions activity (Ring et al., 2017). Post-PD comparisons of the teachers' conceptions on Day 1 of the PD to their conceptions on Day 5 of the PD can help facilitators measure and evaluate the impact of the professional development's activities, which aligns with our own future research plans. This research could then allow facilitators to adjust the activities to better serve the needs of professional development participants. Understanding the conceptions of STEM education held by teachers will allow administrators, professional development facilitators, and others involved in improving STEM education to better support teachers implementing STEM in their classrooms.

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