INTRODUCTION

Enthusiasm for the idea of integrated Science, Technology, Engineering, Arts, and Mathematics (STEAM) learning because of its appeal to diverse learners (Kang, Park, Kim, & Kim, 2012), multiple forms and expressions (e.g., through problem-based learning and design thinking) (Cook & Bush, 2018), and promise in attracting a wider range of learners to the fields of science and mathematics (Masata, 2014) has generated a rapid response in implementation of STEAM initiatives in elementary schools. Research in STEAM has shown its effects on increasing students motivation, engagement, and effective disciplinary learning in the subject areas that comprise its acronym (Bush & Cook, 2016; Kang, Park, Kim, & Kim, 2012). Moreover, this literature highlights the importance of art integration into STEM to appeal to more types of learners (Ahn & Kwon, 2013; Bequette & Bequette, 2012; Hwang & Taylor, 2016; Wynn & Harris, 2012) and deepen students’ interests in science and mathematics as they develop their abilities in integrated thinking and problem solving (Yakman, 2012).

Seeing its appeal both to the growing research base in science, mathematics, and integrated learning and in practitioner-based professional organizations, teachers are planning STEAM lessons by drawing from multiple curricular resources. Sometimes teachers utilize vetted lessons from professional journals such as the National Science Teaching Association's Science and Children or the National Council of Teachers of Mathematics' Teaching Children Mathematics; sometimes they tweak ready-made STEM curriculum from kit-based curricula such as Engineering is Elementary©; and often they pull from online resources (e.g., Teachers Pay Teachers, Pinterest) that have no vetting. Whatever means teachers use to build their STEAM curricula, the aim should be to connect students to relevant and meaningful instruction that deepens students interest and experience with interdisciplinary science and mathematics. While it is great to have such excitement surrounding STEAM teaching, professional developers and researchers are working on how to best support teachers to develop their own well-articulated and evidence-based STEAM lessons. As teachers equip themselves to design and develop new STEAM programs...
and curriculum at their schools, support from professional development and research is needed to ensure best practices are well underscored in STEAM curricula.

Our professional development work focuses on supporting teachers to design and develop their own STEAM curricula and draws from known best practices in science, mathematics, and integrated learning (Czerniak, 2007). This work focuses on the development of elementary teachers’ planning practices as they build STEAM experiences in their grades 3–5 classrooms. The purpose of this instrumental case study is to understand elementary teachers’ planning of the STEAM curriculum during a two-year professional development experience. This research is guided by the following question: What planning practices developed or changed during a professional development experience? For the purposes of this article, we conceptualized the curriculum as actual students’ experiences, opportunities, and learning. This definition allows us to extend our view beyond a planned unit-of-study (referred to as a “lesson” in this manuscript). In analyzing teachers’ planning practices, this instrumental case study yields recommendations on the unique considerations for teachers as they engage in STEAM teaching and learning.

2 | CONCEPTUAL MODEL

This study derives from the work of Quigley, Herro, and Jamil (2017) which presents a conceptual model for designing STEAM instruction. Focusing on the instructional content (while acknowledging that the learning context plays an instrumental role in the effectiveness of instruction), Quigley et al. note “STEAM has been conceptualized through a narrow disciplinary approach that does not provide educators with guidance on how STEAM is different from STEM” (2017, p. 1). As efforts are being made to articulate what constitutes sound design of STEAM lessons, these researchers attempt to define what makes STEAM unique from other integrative pedagogical approaches. In doing so, they articulate a “STEAM Teaching Model.” This model informs our professional development work and also serves as the conceptual framework we used to conduct our case study.

The STEAM Teaching Model is derived from extensive work with middle school teachers (though it may also be used in elementary school settings) and centers on (a) real-world applications that have no definitive solution; (b) the need for multiple disciplines to address the problem; and (c) the need for students to use collaborative skills in finding a solution. The two domains within the conceptual model are Instructional Content and Learning Context. The Instructional Content domain, within which our work is most directly situated, is related to the ways in which the teacher organizes, prepares, and delivers the content to the students. This domain includes problem-based delivery, discipline integration, and problem-solving skills. Within this domain, STEAM curricula frames learning in a problem or issue for which there is no one correct answer (Hmelo-Silver, 2004) and for which the authentic or real-world nature of the problem is important. Instruction is inquiry-rich, creative, and prioritizes all the contents and practices in STEAM through purpose-driven exploration. In our study, we approached the Instructional Content domain by looking into the content and practices teachers were drawing upon in their lessons.

The STEAM Teaching Model also informs our work related to the Learning Context, which includes instructional approaches, assessment practices, and equitable participation. In this domain, STEAM positions technology and art integration as purposeful and meaningful supports to deep and experiential learning, assessment is formative and instructional decisions are data-driven and iterative, and there is a privileging of students choice and appreciation of diverse students needs and interests. In this study, we approached the Learning Context by exploring how teachers were making pedagogical choices and engaging in assessment practices. Considering our data through the lens of the STEAM Teaching Model helped us understand how the components of STEAM curricula should incorporate these elements to maximize the benefits of this pedagogical approach to learning.

3 | SYNTHESIS OF RELEVANT LITERATURE

3.1 | STEAM teaching and learning

A central tenet of STEAM teaching and learning is to move beyond traditional instructional practices that have core subjects separated to purposefully cross or even transcend disciplinary boundaries as students begin to solve complex and authentic problems (Bush & Cook, 2016). Jin, Chong, and Cho (2012) asserted from their work in STEAM teaching and learning the importance of real-world connections in problem solving to fully engage students in multiple disciplines. As such, STEAM instruction positions students to solve authentic problems that ultimately aim to make the world a better place (Cook & Bush, 2018). A key component of STEAM is the inclusion of the “arts” which focus on creativity, aesthetics, and personal expression (Cook & Bush, 2018). Proponents of STEAM argue that the arts can be defined broadly and incorporated through various representations such as design, computer graphics, arts as expression, performing arts, or creative problem solving (Herro & Quigley, 2016).

While at present there is limited evidence about students outcomes from STEAM instruction, there are a growing number of studies addressing the impacts of STEAM curricula on students. Despite the limited research delving into students outcomes in STEAM, the literature base does show promise.
Kwon, Namb, and Lee (2011) found that a computer-based arts and design STEAM model had a positive effect on students' creativity. In another study, Miller and Knezek (2013) noted increased elementary students' engagement, self-confidence, and personal discovery that could ultimately lead students to new career paths or opportunities. Furthermore, STEAM education has been shown to facilitate students' interest in and understanding about science and technology and to develop their abilities in integrated thinking and problem solving (Bequette & Bequette, 2012; Wynn & Harris, 2012; Yakman, 2012).

Recommendations have been made for teachers as they develop STEAM curricula to include a focus on process skills, the use of national and state standards to drive the planning of thematic units, and the use of strong and meaningful themes (Park Rogers & Abell, 2007). Researchers have also suggested inquiry-based learning to connect science, mathematics, and the real world (Bush & Cook, 2016; Quigley et al., 2017). We based our professional development on these recommendations by considering not only the guiding standards but also ways we could connect inquiry practices to authentic local contexts in ways that would effectively integrate STEAM content areas.

3.2 | STEAM professional development

Literature indicates that professional development in STEAM has employed various approaches. Miller and Knezek (2013) found in their STEAM professional development that the incorporation of a specific focus on collaboration and creativity though technological problem solving led to an increased effect on science and mathematics achievement. Similarly, when Herro and Quigley (2016) positioned middle school educators as the creators of rich problem-solving scenarios during an intensive one-week professional development, teachers perceived technology and collaboration as initial access points for transdisciplinary thinking (extending rather than integrating disciplinary boundaries in problem solving). As a result of the professional development, teachers reported an increased understanding of STEAM as a method to teach content enhanced by collaborative opportunities and technology. The researchers found, however, that longer-term, more sustained professional development is necessary to truly transform practice. Bush and Cook (2016) reveal the power of sustained professional development through community and university partnerships. Their work showcases the benefits of collaborating with stakeholders in order to create authentic and meaningful opportunities for teachers that have the potential to fundamentally change how they envision their classrooms.

3.3 | STEAM planning practices

The Educators Evaluating the Quality of Instructional Products (EQuIP) rubric for the Next Generation Science Standards (NGSS) serves as one reflective framework for teachers, focusing on starting lessons with a phenomenon and designing solutions to problems throughout, building toward a larger standard through looking at individual components. Ewing (2015) cautions that, while the small pieces that make up a lesson are important, solely focusing on them could lead to “a bunch of disconnected lessons that do not support students in being able to demonstrate their understanding of the performance expectations at the end of instruction” (p. 14). The elements of inquiry and being students-centered are foundational in STEAM curricula (Connor, Karmokar, & Whittington, 2015) and pedagogical strategies such as problem and project-based learning as well as design thinking have been promoted as ways to conceptualize building STEAM curricula (Cook & Bush, 2018). These strategies include some of the hallmarks of STEAM teaching: arts integration, non-traditional assessments, and technology integration (Quigley & Herro, 2016; Quigley et al., 2017).

Still, teachers struggle with implementing these research-identified best practices in ways that might move beyond simply adding components onto a standard (for example, art is realized as students asked to draw a picture of the water cycle) or checking off each discipline in the STEAM acronym (Cook & Bush, 2018). Because STEAM runs “counter to the single content area and standards-driven curriculum training teachers receive” (Quigley & Herro, 2016, p. 424), it becomes critical to provide support on how each discipline fits together with other disciplines to create a robust and richer story to engage students.

4 | METHODOLOGY

We conducted an instrumental case study (Creswell, 2013) to understand how elementary teachers planned lessons in a two-year-long professional development program focused on STEAM teaching and learning. A case study is defined as an exploration of a bounded system over time through detailed, in-depth data collection involving multiple sources of information (Creswell, 2013; Stake, 1995). Merriam (2009) defines an instrumental case study as one where the case itself is a placeholder for a phenomenon of interest. We chose to conduct an instrumental case study since this approach allowed for a detailed and in-depth exploration of teachers' STEAM curriculum planning practices as the phenomenon of interest. Specifically, we sought to understand the planning practices teachers use when developing STEAM curricula (actual opportunities, experiences, and learning) that is enacted in complex environments such as elementary classrooms, which have tended to silo rather than integrate disciplines (Czerniak, 2007; Watanabe & Huntley, 1998). Analyzing teachers’ development of STEAM curricula over time allowed us to highlight the strategic and iterative choices teachers made as they planned, implemented, and reflected upon STEAM teaching and learning during the two-year
professional development experience. An instrumental case study was selected as a methodological approach that allowed for a detailed, in-depth exploration in a manner that would allow for insights into what teachers consider when experiencing this unique pedagogical experience. In an effort to draw conclusions about STEAM planning practices, we analyzed 25 teachers’ STEAM lesson planning documents across a semester (e.g., multiple lesson plans, sometimes multiple days) to look for trends and patterns across their development as STEAM curriculum planning practitioners.

4.1 | Participants

This instrumental case focused on 25 elementary teachers (five teacher teams; grades three through five, except for two teachers who had recently changed grades levels to grade two) and five instructional coaches across five schools in a large, urban school district in the Midwest during a two-year professional development experience. These teachers from five different schools in the same district participated in a STEAM professional development program for two years, which included approximately 130 hr of sustained professional development during the school year.

The district was a large urban district in the Midwest classified as “Needs Improvement/Progressing” and ranked below the state average in grades/K5 mathematics and science achievement. Teachers’ classroom experience ranged from two years in the profession to veteran teachers (20+ years in the classroom) and educational attainment ranged from a bachelor’s degree to multiple graduate degrees in education (not in the science or mathematics disciplines). The professional development drew on two research-based reform models: problem-based inquiry, shown to improve urban and minority students’ achievement and engagement in mathematics and science (Bush & Cook, 2016; Calabrese Barton, 2007); and interdisciplinary learning, also shown to enhance learning outcomes and engagement for mathematics and science (Czerniak, 2007). The professional development program included an initial component for one STEAM coach per school and continued with instructional coaches leading building-level professional learning communities for participating teachers as they implemented STEAM inquires throughout the year.

4.2 | STEAM lesson planning

Teacher teams planned multiple STEAM lessons throughout the professional development as they followed their district pacing guide to incorporate relevant science and mathematics standards (both content and practices for each) and expectations throughout each year. Each teacher team planned at least four STEAM inquires, usually comprised of several lessons each. Most teachers worked in small grade-level teams within their school to develop their STEAM lessons, most often in collaboration with the school STEAM Lab teacher (who was also the designated building instructional coach for that school). Teachers were given a basic template (see Appendix for final version) to build and reflect on these inquires and were asked to focus on inquiry processes and standards alignment as well as both formative and summative assessment. Throughout the professional development experience, teachers were provided models and instruction in problem-based learning and design thinking, and they were taught how to use the 5E learning cycle (developed by the Biological Sciences Curriculum Study; BSCS, 2006) approach to planning inquiry-based learning experiences. With regard to design thinking, the Design Thinking© framework (Hasso Plattner Institute of Design at Stanford, 2010) was presented as consisting of five phases (i.e., Empathize, Define, Ideate, Prototype, and Test). Like problem-based inquiry, this framework is most useful for tackling problems that are ill-defined or unknown. They were also introduced to examples of embedding technology to teach content. Teachers also experienced multiple modes of expression in the arts (i.e., music, dance, visual arts, media, theater) and learned how to effectively coteach with knowledgeable others (i.e., expert teachers, community partners, etc.) to enhance STEAM curricula. Teachers used the Plan-Do-Study-Act (PDSA) cycles (Bryk, Gomez, & Grunow, 2010) to plan, implement, reflect upon, and improve their STEAM curricula. During these PDSA cycles, teachers received feedback on their lesson plans from professional developers and well as peers.

4.3 | Data collection

After each lesson was implemented in the classroom, teachers reflected on the experience. Their reflections informed changes in future curricular planning. Thus, we were able to ascertain how these reflective conversations ultimately took shape in their lesson planning documents themselves (actual changes rather than teachers’ intended modifications). This intentional choice to focus primarily on the lesson planning documents was made because we wanted to showcase the development in teachers’ actual planning practices and how those reflections were used to change plans for their future lessons, rather than in their debriefing and reflective sessions with others. Reflection prompts included questions such as (a) Did the lesson go as well as you had anticipated? (b) Did the students outcomes meet your expectations? (c) Would you consider doing this lesson again? If so, how would you change it? Or, why would you choose not to change it? (d) Will you use this teaching approach again?
To explore how teachers aligned lessons to curricular standards and what instructional practices they chose to use to teach STEAM, the STEAM lessons provided credible data for understanding teachers’ thinking because planning the inquiries required them to anchor instruction in STEAM disciplinary standards, establish goals for the lesson, plan instruction for helping each and every student meet those goals, and assess the goals. The lesson plans provided insight into the process of how teachers constructed STEAM lessons at four different points throughout the professional development.

### 4.4 Data analysis

The data analysis procedure for this study was both an inductive and deductive process that consisted of a thorough review of teachers’ documents (STEAM lesson planning documents) and reflections from the PDSA cycles and ultimately yielded codes to describe teachers’ instructional choices over time. Using the STEAM Teaching Model (Quigley et al., 2017), we framed our analysis of teachers’ planning documents and reflections by considering both instructional content and learning context. Because we were interested in how teachers were using their knowledge of STEAM as well as their knowledge of their students and classroom environments to plan, we wanted to focus on what teachers articulated and detailed in their actual STEAM lesson plans as they synthesized all of this knowledge. Deductively, given the focus on inquiry processes and standards alignment, data were coded for STEAM content and practices, pedagogical strategies, and assessment practices. Then these categories and corresponding evidence were inductively examined to understand how teachers’ lesson planning practices in STEAM evolved over the course of the professional development experience. Throughout this part of the process, researchers coded documented evidence to identify emergent patterns within each category of content and practices, pedagogical strategies, and assessment practices. Researchers compared codes until consensus was reached. Once complete, the codes were examined for overlap and redundancy and collapsed into broad themes (Creswell, 2013). Themes that emerged were triangulated within and across data sources, with careful attention to maintaining an audit trail back to the original data (i.e., lessons and PDSA cycles). Collaborative coding enabled the authors to bring their content expertise of science, mathematics, and STEAM to the analytic process.

### 4.5 Validation of findings and limitations

Construct validity was strengthened through the triangulation of perspectives and data sources. Triangulation of perspectives (from a science educator, mathematics educator, and STEAM educator) was conducted as STEAM researchers/professional development providers met multiple times to identify themes and analyze the data. The triangulation of data sources was accomplished through the analysis of multiple planning documents. All participants were fully informed of the intent of the study and the nature of reflective conversations allowed them to represent their own experiences. As is true with case studies, there are limitations for advancing grand generalizations (Stake, 1995). The purpose of this study was to present this particular case of elementary teachers involved in a shared professional development experience, not to generalize beyond the setting. While the professional development was offered in only one school district in the Midwest across five schools, it allowed us to explore the planning of STEAM curriculum in a large urban district with high percentages of students from underrepresented populations.

### 5 FINDINGS

The purpose of this instrumental case study was to understand elementary teachers’ planning of the STEAM curriculum during an ongoing sustained professional development experience. This research was guided by the following research question: What planning practices developed or changed during a professional development experience? The findings are presented here to demonstrate our understandings using specific quotes or written documents from teachers as supporting evidence. Findings are organized by the following domains of the STEAM Teaching Model: Content and Practices, Pedagogical Strategies, and Assessment.

#### 5.1 Content and practices

##### 5.1.1 Standards and objectives

Developing curricula for STEAM necessitates the use of several disciplines, each with its own set of content and practices. When exploring how teachers were connecting to the content and practices of the multiple disciplines drawn upon in STEAM, we noticed teachers over time used fewer and more targeted standards (and clearer connections) as they developed inquiries. At the beginning of the professional development, teachers used multiple standards for a single discipline and as a consequence, the focus of the curriculum was difficult to pinpoint and only touched superficially and/or tangentially on some standards.

Another trend we noticed was that teachers became more specific about what their students would be doing to engage
in targeted standards. Early in their planning experiences, teachers incorporated more vague descriptions of what students would be doing. Later in their professional development experience, however, teachers articulated students tasks more specifically connected to problem statements, which in turn helped draw out the disciplinary content and practices in authentic ways. As seen in the following example, Figure 1 shows the multiple science standards (just one of the STEAM discipline areas for which several standards were listed without describing what students would be doing to target those standards) of focus in one group’s first STEAM lesson. The second part of Figure 1 shows the same teacher group’s final STEAM lesson in which they specified the three dimensions of one performance expectation in science and clearly articulated what students would be doing to target that standard. Because many of the teachers did not articulate how students would be expected to demonstrate their understanding of the standards, we added a more explicit header to the planning sheet after the first cycle of lesson planning.

Regarding science and mathematics standards, oftentimes teachers would focus only on practices instead of on the content of these disciplines. For example, one group stated their focus was to develop models for how the earth systems (e.g., hydrosphere, biosphere, geosphere, atmosphere) interact and had students complete a map as their model. Their plan stated, “Focus on 5ESS2.A: Develop a model to describe how spheres interact; Task: Create a map of the neighbors and topography on your farm.” While the teachers required topographical and dimensional information on the model (i.e., map) development, they did not include the requirement of content about earth systems. Although this tendency to neglect content and focus on practices stayed somewhat present even throughout the professional development, we did see a shift toward teachers including cross-cutting concepts and science and engineering practices, which helped teachers stay focused on the multi-dimensional performance expectations.

5.1.2 | Defining art

With regard to arts standards, teachers came to define art as culture, empathy, and expression (as opposed to skill development such as drawing or crafting). At the beginning of the professional development, art integration often included drawing or digital design (i.e., “draw a picture to show” or “create a 3D CAD image that shows”). Later in the professional development, however, most teachers elected to use the Design Thinking® framework to embed arts into the problem statement that guided the lesson. One teacher group, for example, required study of culture and art in a nearby rural area to design a lamp that complemented the history of the region. As their project focused on energy, they asked students to design a lighting source that would be useful to families who live in homes without electricity. As part of their STEAM lesson, students watched a documentary and wrote reflective essays on life in a rural area near them as they compared homes they live in with homes sometimes found in this area. In fact, empathy building became a central component of the experience of the STEAM curricula, which will be discussed further in the next section.

<table>
<thead>
<tr>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
</tr>
<tr>
<td>4-PS3-2, 4-ESS3-1, 4-ESS3-1</td>
</tr>
</tbody>
</table>

Energy transfer, convert energy from one form to another, energy derived from natural resources

<table>
<thead>
<tr>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
</tr>
<tr>
<td>Performance Expectation: 4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by heat Disciplinary Core Ideas: PS3.B Conservation of energy and energy transfer Cross Cutting Concepts: Energy and Matter: Energy can be transferred in various ways between objects.</td>
</tr>
</tbody>
</table>

Students will investigate different materials to determine which will serve as the most effective insulator for the coat.

FIGURE 1 A teacher group’s early STEAM planning that incorporates multiple science standards without articulation of how students would engage in these standards. Later, the same teacher group’s later STEAM planning that incorporates one performance expectation with clear articulation of how students will address the multiple dimensions of this standard.
5.1.3 | Broadening the definition of technology

When integrating technology, teachers began the professional development by often selecting technology standards (i.e., International Society for Technology in Education (ISTE), 2016) that were not always appropriately linked to the problem exploration, but over time broadened their definitions of technology to incorporate strategic use of tools and materials. For example, teachers embedded informed decision-making regarding materials and tools with which to build a prosthetic leg. Teachers initially thought of technology as only digital devices; however, when they learned that the definition of technology was practical tools that help solve problems, teachers embraced more types of tools that could be considered technology. This shift was helpful in enabling teachers to use what tools made the most sense with regard to supporting their learning objectives, rather than trying to force fit novel technology into the STEAM curricula.

Teachers shifted to an empathy-driven approach to art-integration and related the arts to personal expression (as opposed to crafting or drawing). Teachers also connected technology to the problem statement, broadening the definition beyond digital applications and gadgetry. This was evidenced by teachers’ willingness to be flexible about how they conceptualized art and technology integration as well as teachers’ developing notions about what the arts and technology disciplines do to support students’ understanding of content and practices.

5.2 | Pedagogical strategies

5.2.1 | Activities versus learning experiences

In terms of pedagogical strategies, our analysis indicated that, initially, teachers often incorporated fun and engaging tasks that did not always connect to disciplinary content or practices to be taught. In many instances, content or practices that were mentioned were not taught deeply and explicitly during the lesson. Thus, content and practices were not taught explicitly, but there were implicit connections to other content that students were expected to make without scaffolding or supports to do so. For example, one teacher group designed a lesson that stemmed from a book about a man in the late 1700s stranded in a blizzard with no electricity, and tasked students with developing a plan to “keep the man alive.” A plethora of standards to which students might connect were listed, but with no parameters or scaffolds listed there was a lack of clear connections to science or mathematics content.

Over time, teachers paid more careful attention to linking tasks with standards and describing these connections. For example, in Figure 3, teachers attempted a similar problem (i.e., helping a giant survive in the cold) but provided specific guidance on the criteria and constraints of the problem. In this example, teachers provided criteria (i.e., create a coat that will keep the giant warm) and constraints (i.e., choose from among specific materials, dimensional requirements for the design) to ensure students were conducting tests of materials to determine the best insulators as well as using specific mathematical concepts to design the appropriately sized coat. This helped to guide students through content and practice standards that directly connected to the problem statement and demonstrated clearer connections to science content standards.

5.2.2 | Specificity in planning

At the beginning of the professional development, teaching strategies were noted frequently without written plans for how they would be employed. Words frequently used in the lessons that contained no description included co-teaching, students choice, and high-level questions. During the course of professional development, teachers were asked to be more specific about their use of these words. Teachers did begin providing more information about how they planned to use these strategies. For example, rather than a strategy listed with no description, teachers described more intentional co-teaching practices. We noticed teacher groups from the same school tackling large-scale STEAM lessons across grade levels. In these instances, teacher groups would plan around the same problem statement but adapt the task slightly to account for different grade level foci. Thus, groups would design one problem statement and align it to many standards and grade levels, showing their abilities to think cohesively and draw out pieces of interest across developmental ages. They described how this co-teaching would necessitate collaborative planning and reflection among colleagues and pinpointed a plan for such professional time.

**FIGURE 2** Teachers define technology standards and describe how students will strategically select materials and tools for their STEAM inquiry
5.2.3 | Literacy connections

Several teachers at both the beginning and throughout the professional development incorporated literacy both as a hook into and throughout the lesson as students were asked to read, write, and communicate. Some teachers used a fiction or non-fiction children's literature book to hook students' interest and set the stage for the problem under investigation. Others incorporated and assessed students through means of literacy (e.g., persuasive arguments, narrative essays outlining textual evidence as support in their research, communicative abilities). Though not required, this tendency to embed English/Language Arts standards into STEAM revealed the extent to which teachers felt immediately comfortable with and knowledgeable about building literacy into their instruction.

5.2.4 | Using the design thinking© framework

As was mentioned in the previous section, teachers displayed an increasing focus on the use of empathy building. As they learned about the Design Thinking© framework (Hasso Plattner Institute of Design at Stanford, 2010), several teachers immediately embraced this model of planning and drew from the steps of design thinking to develop lessons that included empathy as a first step. Problem statements incorporated empathy-building experiences; for example, one group designed a STEAM lesson around an elephant who lost his leg in a land mine (adapted from an Engineering is Elementary© unit). As a first step to developing a prosthetic prototype for the elephant leg, students had to attempt tasks without the use of one leg and try on various attachments to consider function, durability, and comfort before designing their own.

5.3 | Assessment

5.3.1 | Challenges with assessment

Teachers seemed to struggle most with assessment both at the beginning and throughout the professional development. Early lessons often included no assessment at all, and when it was included it was vague and non-descript. At times, plans for assessment instruments were mentioned but not what would be assessed. For example, one teacher group stated, “Once models have been created, students will assess their final products using a rubric,” though they gave no descriptors as to what would be assessed. Another group stated they would “ask questions to determine students understanding,” but did not articulate how or through what means they would do so. As greater emphasis during the professional development sessions was placed on assessment, teachers did incorporate more plans for assessment; however, these plans continued to be loosely connected to the content and practices of the standards.

5.3.2 | Summative assessment

With regard to loose connections to content and practices, sometimes teachers only assessed mathematics or science. Other times they only assessed 21st Century Learning such as teamwork or creativity. Overall, the assessments did not holistically assess the various disciplines of STEAM, were lacking in detail and suffered from missed opportunities. Some teachers did include art and technology assessments; however, it was apparent some teachers were unsure of how to create meaningful and task-relevant assessments for the multiple disciplines of STEAM (e.g., multi-discipline content and practices as well as 21st Century Learning skills).

5.3.3 | Formative assessment

Teachers often had the performance task or product as the final assessment of the culmination of the learning experience without articulating plans for formative assessment along the way. All too often, content and practices were assumed in the summative assessment and not measured or articulated as a requirement in the presentation of the final product or performance task. For example, the group who asked students to study energy for use in homes with no access to electricity incorporated an assessment that was to make a “functional solar oven.” As such, students could create and explain how they made a functional solar oven but not be required to understand or describe how solar energy works and the benefits/challenges of using it as an alternative energy source.
5.3.4 | Strategic use of questions

As teachers gained more experience planning STEAM lessons, they did focus more on questioning and engagement. They asked higher level questions directly connected to science and mathematics learning. One group asked students, “What makes the best insulator? Support your answer with evidence.” More formative assessment was included over time and took the form of focusing on students reasoning (e.g., using claims, evidence, reasoning format or argumentation). More intentional use of questioning about science and mathematics concepts and reasoning was also noticed over time. In Figure 4, teachers asked questions about science and mathematics content and practices.

Though it remained a struggle to incorporate all of what teachers wanted to assess in their STEAM lessons onto one summative rubric, teachers did employ the use of formative assessment to prioritize the science and mathematics in their lessons.

6 | DISCUSSION AND IMPLICATIONS

The STEAM Teaching Model (Quigley et al., 2017) was a useful tool for analyzing teachers’ STEAM planning documents as it enabled us to examine themes and common patterns centered on the domains of Content and Practices, Pedagogical Strategies, and Assessments. Overall, we learned that at the beginning of our professional development program we were asking teachers to integrate content and practices across disciplines in ways in which, for the most part, they had not been asked to do nor were prepared to do in their own teacher preparation programs. This is consistent with Asunda and Mativo (2015), who contend that teachers need experiences collaborating across disciplines and opportunities to practice identifying science and mathematics content and practices in integrated STEM instruction.

STEAM instruction is vastly open-ended and complex, and it takes time to become comfortable teaching in a way where one cannot possibly anticipate every question or solution path a students might present (Cook & Bush, 2018). Teaching in a way that meaningfully integrates the STEAM subjects is different from traditional siloed teaching and can be challenging at times, especially in the area of assessment (Herro & Quigley, 2017). This type of instructional environment requires a great amount of flexibility on the part of both the students and the teacher. In this environment, there is no way to anticipate every question a students may ask, every piece of knowledge from each content area that a students may access, or the direction the lesson may take. Here, the analysis of 25 teachers’ planning documents indicated growth in the following areas (a) tighter alignment to fewer standards; (b) more meaningful integration and broader definitions of arts and technology; (c) increased use of formative assessment through strategic questioning. However, analysis also indicated persistent difficulties in summatively assessing the multiple disciplines of STEAM.

At the beginning of this journey, lessons were often fun and engaging for students but lacked deep alignment with disciplinary content and practices (consistent with cautions about integration from Park Rogers & Abell, 2008). Lessons were often aligned to standards, but without a rich description of what students would do to meaningfully address each aligned standard. Work was definitely needed to ensure the assessment used for the lesson measured the standards the lesson was purported to address. By the end of the 2-year professional development, teachers had grown multidimensionally in their ability and confidence to implement integrated STEAM instruction. We found that teachers better honed in on key standards of focus and provided richer descriptions of how students were engaged in those standards during the lessons. Teachers were more intentionally choosing to co-teach and they also self-selected more specific strategies to focus on as areas for instructional growth rather than trying to tackle too much at once.

Over time, the use of the Design Thinking© framework (Hasso Plattner Institute of Design at Stanford, 2010) and a focus on empathy increased and was found to be a strong access and entry point to students learning. Through our

**FIGURE 4** Formative assessment prompts focusing on science and mathematics content and practices

Formative Assessment Plan: Please include specific prompts you will ask students. Some examples of formative assessment prompts are included below. Please add to this section.

4th Grade:
- Child created prosthetic
- ABCD diagram of the prosthetic

Questions we plan to ask to students:

Science
1. What would be the best material to make the prosthetic?
2. Why would that material work best? Why not _________ material?

Math
1. How many centimeters long should the leg be? Why do you think that?
2. How long is the actual leg?
3. What is the difference? How close was your estimate?
work, we have found one of the most powerful aspects of integrated STEAM is the incorporation of the empathy, which is echoed in the work of Walther, Müller, and Sochacka (2017) that focuses on empathy in engineering. In our work, it was the arts through which personal expression was explored. Research has shown the inclusion of the arts to appeal more broadly to all students, especially those who may not see themselves as interested in STEM and various populations of students such as students with disabilities (Hwang & Taylor, 2016). While the work of Herro and Quigley (2017) indicated teachers struggled persistently with how to address the A in STEAM, the teachers here utilized the focus on designing for others through the process of design thinking to evoke the creative elements of the STEAM experience. When teachers implemented STEAM lessons that sought to problem solve on behalf of others or design with someone else in mind, their sense of purpose and engagement in the lesson increased.

Additionally, art and technology were included to varying degrees in the lessons, though the accompanying assessments generally did not include an arts or technology component. Despite this, teachers' integration of arts showed more focus on relevance and personal expression. Teachers more holistically considered how the arts could be meaningfully incorporated into their STEAM lessons, which in part embraces Bailey's (2016) definition of recognizing the role of aesthetics, beauty, and emotion to solve a problem. Teachers also broadened their definition of technology, embedding many of the tools they experienced in the professional development. This is consistent with Herro and Quigley's work with teachers in which they showed that "modeling the use of technology as a learning tool (for creating, communicating and demonstrating understanding) wherein teachers assumed the role of students enhanced STEAM learning" (2017, p. 433).

Finally, access to the integrated curriculum was most natural for teachers through literacy. From the beginning to the end of the professional development, teachers leaned heavily on stories to inspire their lessons. This provided a starting point for future professional development providers to stimulate interdisciplinary curricular development using literacy as a springboard to STEAM.

Assessment building remained elusive, but teachers used more and better formative assessment prompts to promote important science and mathematics content and practices. Although there was progress made regarding focusing in on specific content and practice standards in which students were most engaged within a lesson, the accompanying assessments still often leaned heavily on only one STEAM subject. We also found that by the end of the professional development, many lessons were deeply engaging students in meaningful science and mathematics learning that was conceptual and inquiry-based in nature, but the assessments that accompanied the STEAM lesson sometimes remained surface-level and procedural in nature. We advocate for more performance-based assessments, which can take on many different forms and include students choice on the product they produce or the process through which they showcase their content understanding, for assessing students learning in STEAM.

The growth in teachers' STEAM instruction from the beginning to the end of this two-year professional development was important in building our understanding of what constitutes sound design of STEAM inquiries. As science teacher educators, it is our role to support teachers in best practices in STEAM instruction. As schools and districts forge new STEAM initiatives and develop curricula for their students, it is important to be mindful that the preparation for all the moving parts of STEAM teaching is unique and traditional preparation is often not sufficient. In our work, teachers showcased many areas in which their planning practices for STEAM grew. The teachers in our study needed support in targeting, articulating, and balancing a focus on the science and mathematics content and practices most essential in their STEAM lessons. Another area in which teachers needed support is in choosing relevant and meaningful arts and technology integration that support content and practice development. Finally, teachers needed support devising assessments that underscore the multi-dimensional outcomes of STEAM learning, which include not only disciplinary content and practices but also 21st-century learning skills. With the momentum STEAM is gaining in elementary schools, we advocate for professional development that recognizes, appreciates, and views the complexity of STEAM instruction as an opportunity to create transformative learning experiences for students.

REFERENCES


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# STEAM PROBLEM-BASED INQUIRY PLANNING GUIDE

**Problem Statement:** Your task is to:

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

**Standards Connections:** Complete the table with all standards (number and text of each standard) directly embedded in your inquiry and briefly describe how students (i.e. what they will actually be doing) will address these standards.

<table>
<thead>
<tr>
<th>Content</th>
<th>Standard</th>
<th>Description of What Students will be Doing to Target this Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>Performance Expectation: Disciplinary Core Ideas: Cross Cutting Concepts:</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>Science &amp; Engineering Practice:</td>
<td></td>
</tr>
<tr>
<td>Arts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematics</td>
<td>Content Standards: Practice Standards:</td>
<td></td>
</tr>
</tbody>
</table>

**Assessment of Problem-Based STEAM Learning:** Specify what and the points at which students will showcase their understanding of the content and practices of STEAM.

**Formative Assessment Plan:** Please include specific prompts you will ask students in the space below.

**Summative Assessment Plan:** Please include below or attach a scoring guide or rubric that comprehensively outlines what students will need to do and know to be successful.