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Abstract

The purpose of this qualitative study was to investigate the conceptions of integrated STEM education held by in-service science teachers through the use of Photo Elicitation Interviews (PEIs) and to examine how, if at all, those conceptions were reflected in teacher-created integrated STEM curricula that include an engineering design challenge. Our findings suggest that different conceptual models of integrated STEM held by teachers lead to different ways of creating, developing, and writing integrated STEM curricula. Additionally, we found that the use of a STEM integration framework and a Framework for Quality K-12 Engineering Education, which guided the NSF-funded project and contextualized this study, were also reflected in the teacher-created curricula. While the process of developing the curricula was not examined, our findings indicate that teacher conceptions of integrated STEM and the frameworks that guided the curriculum development process play a significant role in what teachers decide to include and emphasize in units they create.

Introduction

While policymakers and educators agree on the importance of improving K-12 STEM education through teacher preparation programs, professional development opportunities, and curricular resources, there remains debate about the nature of integrated STEM models (Bybee, 2013; Ring, Dare, Crotty, & Roehrig, 2017; Roehrig, Moore, Wang & Park, 2012). Thus, understanding the conceptions teachers hold regarding integrated STEM education is an important first step in implementing reforms that call for increased integrated STEM education in K-12 schools. In particular, it is imperative that K-12 *science* teachers develop an understanding of what integrated STEM education could look like in the classroom, as reform documents suggest that integrated STEM is most likely to be implemented in science classrooms (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies [The National Academies], 2007; NGSS Lead States, 2013). Without knowledge of teachers' beliefs and understandings related to integrated STEM education, the probability that it will be used in a teacher's classroom, or more specifically used *effectively* in a teacher's classroom, is small (Roehrig et al., 2012). This study addresses the following research questions: (*1) What are the important characteristics of integrated STEM education according to K-12 science teachers as identified through their self-described conceptions of STEM?;* and (2) *How, if at all, do integrated STEM curricula developed by teams of teachers reflect the teachers' conceptions of STEM?*

Literature Review

Integrated STEM Education

The benefits of integrated curricula, which draw from multiple disciplines in purposeful ways, have been well studied. Furner and Kumar (2007) suggest that using an integrated curriculum provides students with a highly relevant, less fragmented, and more stimulating learning experience than traditional disciplinary curricular approaches. Integration allows students to determine when to apply their knowledge and encourages them to examine relationships between multiple concepts resulting in more robust understandings of those concepts (Froyd & Ohland, 2005; Stein, Carnine, & Dixon, 1998). Other benefits to integrated curricula are that they are more student-centered (Czerniak, Weber, Sandmann, & Ahern, 2005), increase student retention (Crosling, Heagney, & Thomas, 2009), and improve students' problem-solving skills (Smith & Karr-Kidwell, 2000). Thus, integrating content is an important aspect to consider when facilitating student learning in the classroom.

Because the nature of 21st century jobs in STEM fields requires individuals to draw upon multiple disciplines, there is a critical need for K-12 students to develop the knowledge and skills necessary to do this.

Bybee (2013) has detailed nine commonly accepted models conceptualizing the integration of STEM disciplines. These models have varying degrees of integration, ranging from STEM as a synonym for a single discipline (e.g., science) to STEM as representing the overlap and intersection of science, technology, engineering, and mathematics. Other definitions of integrated STEM education offer broader, more pedagogically-based definitions than the models offered by Bybee (2013). Breiner, Harkness, Johnson, and Kohler (2012) define the practice of STEM integration as the shift from traditional lecture-based classrooms to the implementation of pedagogy that involves more inquiry and problem-based learning approaches. Moore, Stohlman, Wang, Tank, Glancy, and Roehrig (2014a) define integrated STEM education as “an effort by educators to have students participate in engineering design as a means to develop technologies that require meaningful learning and application of mathematics and/or science” (p. 38). This definition of integrated STEM education specifically emphasizes the integration of engineering into science and mathematics classes. Similarly, many frameworks for STEM education have placed a strong emphasis on incorporating a strong engineering component in science disciplinary content and process; this strategy has the potential to increase both student learning (Moore et al., 2014a; National Research Council, 2011; 2012) and interest in STEM-related careers (Guzey, Moore, & Harwell, 2016; Guzey, Moore, & Morse, 2016). Clearly, there are a variety of definitions and models of integrated STEM education. Bybee (2013) suggests that while it is not important that one model be chosen as the exemplar or that there be a one-size-fits-all definition, it is important that teachers, administrators, school districts, and policy-making agencies consider their own conceptions of integrated STEM to operate better as advocates for STEM at the local level. Teachers are then faced with the difficult task of determining what integrated STEM education means for them at a personal and practical level.

Teacher Conceptions

Research indicates that teachers’ conceptions of teaching influence their practice (Gow & Kember, 1993; Trigwell, Prosser, & Waterhouse, 1999). Because research has shown that different approaches to teaching are associated with different approaches to learning (Gow & Kember, 1993; Trigwell et al., 1999), how a teacher conceptualizes teaching can have a substantial influence on student learning in the classroom. For example, teachers who believe that teaching should be active, or include multiple forms of interaction with students, have higher student achievement in their classrooms compared to teachers who do not believe that active teaching is important (Rowan, Correnti, & Miller, 2002). Further, believing that learning should be facilitated rather than transmitted leads to deeper content learning for students (Kember & Gow, 1994). Teacher conceptions and beliefs become particularly important when considering educational reforms that require not only changes in instruction, but changes in the way one thinks about subject matter.

Up until the early 2000s, STEM education was conceptualized simply as the four separate disciplines of science, technology, engineering, and mathematics (Sanders, 2008), similar to Bybee’s (2013) “quartet of separate disciplines” (p. 76). Since that time, however, STEM education has become more synonymous with *integrated* STEM education (Moore et al., 2014a; Sanders, 2008; The National Academies, 2007), something that more resembles Bybee’s (2013) “complementary overlapping across disciplines” (p. 78). This is a major shift that necessitates substantive changes in teachers’ conceptualizations of STEM (Asghar et al., 2012). This is of high importance, as teachers are less likely to alter their pedagogy or make fundamental changes to the nature of their instruction if their conceptions of teaching do not change (Kember & Kwan, 2000). Additionally, research has found that it is difficult to separate teachers’ conceptions of STEM *content* from teachers’ conceptions of what it means to *teach STEM*. For example, Ring et al. (2017) found that in-service science teachers conceptualized STEM content in eight distinct ways, but they increasingly supported their conceptions with pedagogical constructs as they developed an understanding of integrated STEM. This indicates that one’s conception of integrated STEM is not solely about content like the models proposed by Bybee (2013), but has pedagogical implications as well, similar to models proposed by Breiner et al. (2012) and Moore et al. (2014a). Thus, as teachers are being asked to implement integrated STEM curricula in their classrooms, it is important to understand how teachers conceptualize integrated STEM education with regard to both content and pedagogy to support them best in this task.

Curriculum

Though educational theorists have debated how best to define the term *curriculum* (Jung & Pinar, 2015; Kliebard, 1989; Portelli, 1987), the commonly-used definition adopted here is *a plan for learning* as proposed by Taba (1962). This general definition allows for modifications to be made by educational professionals based upon their context (van den Akker, 2004). Curricula can also be divided into three forms: (a) intended – the visions and intentions of a written curriculum; (b) implemented – curriculum as interpreted and taught by its users; and (c) attained – the learning experiences and outcomes of the learners (van den Akker, 2004). This definition and these three forms of curricula are useful when considering curriculum analysis; for this study the focus was on intended curricula.

Curriculum development is a critical component of teachers' responsibilities (Clandinin & Connelly, 1992). Deciding what content should be taught (curriculum design), how it should be taught (curriculum construction), and when it should be taught (curriculum mapping) are all crucial decisions that must be made when developing new curricula (Remillard, 1999). Research has shown that how teachers conceptualize these aspects of curricula influences how they write curriculum and implement it (Brown, 2003; Cheung, 2000; van Driel, Bulte, & Verloop, 2008). However, current research concerning teachers' development of integrated STEM lessons and curriculum units is limited; further, research connecting teachers' conceptions of integrated STEM to curriculum writing is lacking. Guzey, Moore, and Harwell (2016) evaluated twenty teacher-developed, engineering-design-based integrated STEM curriculum units using their self-developed STEM Integration Curriculum Assessment (STEM-ICA) tool, but this tool did not take into consideration teachers' conceptions of STEM. Roehrig et al. (2012) examined the extent to which engineering was situated in teacher-developed engineering-integrated lessons, but again did not consider teachers' conceptions of integrated STEM. Wang, Moore, Roehrig, and Park (2011) began to fill this gap in the research by exploring three teachers' perceptions of integrated STEM practices, basing the work on teachers' experiences in both writing and implementing engineering-integrated lessons in their classrooms. While the work of Wang et al. (2011) attempts to connect teacher perceptions and curricula, the focus of this study is primarily on connecting teachers' beliefs to classroom practice (*implemented curricula*) rather than to a written curriculum product (*intended curricula*). To this end, the present study extends the work of Ring et al. (2017), which explored in-service science teacher conceptions of integrated STEM through the analysis of teacher-created representations, or conceptual models, of integrated STEM education and identified eight distinct models. This study aims to understand more fully these conceptions and identify key characteristics of STEM integration that may influence teachers' curricular decisions.

Methods

Context

Forty-five K-12 science teachers participated in three weeks of summer professional development as part of a large, five-year NSF project designed to promote K-12 integrated STEM education using both a STEM integration framework (Moore et al., 2014a) and a Framework for Quality K-12 Engineering Education (Moore, Glancy, Tank, Kersten, & Smith, 2014b). The STEM integration framework (Moore et al., 2014a) was used to help teachers better understand relationships between science, technology, engineering, and mathematics concepts and to consider ways science, technology, engineering and mathematics could be taught within the context of a single classroom. The Framework for Quality K-12 Engineering Education was introduced to help these *science* teachers better understand ways in which engineering could be integrated in their classrooms as science teachers often lack any experience with engineering.

The data collected for this study were part of the third year of the funded project, where 21 of the participating teachers previously had participated for one or more years. The project's guiding paradigm of STEM integration involves the merging of STEM disciplines to: (1) deepen student understanding of STEM disciplines, (2) broaden student understanding through exposure to socio-culturally relevant STEM contexts, and (3) increase interest in STEM disciplines (Moore, 2008).As part of the project, K-12 teachers created integrated STEM curricula for use in their classrooms, working in teams of one to three teachers alongside a classroom coach. The curricula created as part of this project were expected to include the components of STEM integration as defined by Moore et al. (2014a) and discussed explicitly during the professional development: (1) a motivating and engaging context; (2) an engineering design challenge that explores the engineering design process and engineering practices; (3) opportunities to learn from failure and to redesign; (4) mathematics and/or science content as main objectives for the activities; (5) student-centered pedagogies; and (6) an emphasis on teamwork and communication. One of the most distinctive curriculum requirements was the inclusion of a client letter. This letter was intended to provide a motivating and engaging context to help introduce the engineering design challenge in each unit. The teams of teachers chose to focus on one of three science content areas aligned to their instructional responsibilities: physical, life, or earth science. During the summer professional development, these teams co-wrote drafts of a curriculum unit that they piloted with students enrolled in a STEM summer camp. Revisions were made to each curriculum during the school year as team members implemented it in their classrooms. Final revisions based on implementation were made and collected as part of the project's overall requirements.

Research Design

This work employed a multiple case study design (Yin, 2014) contextualized within the aforementioned project. A subset of the teachers involved in the larger project comprised the three separate cases in this study. Each case was defined as a team of three teachers and the curriculum unit they co-developed. The teams of teachers were chosen for this study using criterion sampling (Patton, 2002). These criteria included completeness of the research data, including individual and team artifacts, as well as representation of each of the three science content areas.

Data Collection and Sampling

At the beginning of the school year following the summer professional development, all teachers participating in the NSF project were asked to draw models representing their conception of STEM integration. To understand these conceptions deeply, teachers additionally participated in individual 30-45-minute, semi-structured photo elicitation interviews (PEIs) (Lapenta, 2011). In these interviews teachers were asked to: (1) share and describe their model of integrated STEM; (2) analyze other conceptual models of integrated STEM based on the work of Ring et al. (2017); and (3) share ways in which they would change their model, if at all, after seeing other models. For the work presented here, analysis of the PEIs was limited to understanding key aspects of the individual's own STEM conceptual model, as the focus of this study is how these conceptions are translated into curricular documents.

Table 1. *Case breakdown by curriculum and teacher participants*

Case	Curriculum	Overview	Teacher 1	Teacher 2	Teacher 3
1	**Soccer Stadium** Elementary (4th & 5th) Earth Science	Students are contracted to help design an environmentally friendly soccer stadium using local resources while learning about renewable and nonrenewable resources, how they are processed, and the resultant environmental impacts.	**Josh** *Years in* PD: 2 *Years Teaching*: 11-15 K-5 Science Specialist	**Trey** *Years in* PD: 3 *Years Teaching:* 0- 5 General (5th grade)	**Kiera** *Years in* PD: 2 *Years Teaching:* 0-5 PreK-6 Science Specialist
2	**GMOs** Middle School (7th) Life Science	Students are contracted to help design a barrier that effectively prevents the cross-pollination of GMO plants with non-GMO plants in adjoining fields while learning about the scientific concepts associated with genetics and heredity.	**Billy** *Years in* PD: 3 *Years Teaching:* 6-10 6th Grade Honors Science	**Jean** *Years in* PD: 1 *Years Teaching:* 6-10 7th Grade Science	**Rick** *Years* in PD: 1 *Years Teaching:* 0-5 7th Grade Science
3	**Mechanical Claw** Elementary (4th & 5th) Physical Science	Students are contracted to design an electromagnetic arm as a replacement for typical arcade mechanical claw games while learning about electromagnets and magnetism.	**Allison** *Years in* PD: 3 *Years Teaching*: 0-5 Grades 4-5 Science Specialist	**Holly** *Years in* PD: 3 *Years Teaching:* 0-5 Grades 4-5 Science Specialist	**Melissa** *Years in* PD: 1 *Years Teaching:* 0-5 PreK-5 Science Specialist

To select a high-quality sample, the first two authors read through the PEI transcripts to determine the level of completeness, quality, and clarity of the interviews. Interviews that were conducted with entire teams instead of with individuals, included off-script questions or too much input from the interviewer, missed key questions, or were too brief in teacher reflection were eliminated from the possible sampling pool. This process resulted in two teams from physical science and one team each from life and earth science. One of the physical science teams was selected due to higher quality interviews, leaving three teams of three teachers as the separate cases (Table 1). The final curricula created by these three teams were then collected to understand how these teachers' conceptions were translated into a written curriculum document.

Analysis

Qualitative analysis was used to understand important characteristics of integrated STEM as identified by teachers, develop individual STEM conceptions profiles, determine the presence of identified characteristics in each curriculum, and identify connections between participants' conceptions and the characteristics represented in their curriculum unit. Due to the heavy textual nature of the data, content analysis (Miles & Huberman, 1994) was used to frame our study of patterns of integrated STEM characteristics in both PEI transcripts and written curriculum documents. PEI transcripts were analyzed by the first four authors using inductive coding methods (Glaser & Strauss, 1967). Using the software Dedoose, one PEI exemplar was openly coded by the authors to identify initial codes and to assure the authors were calibrated in the way they used codes (Wasser & Bresler, 1996). After developing an initial set of codes, the authors coded the remaining PEI transcripts in teams of two, adding codes as necessary. Discussion, first within and then across the pairs of authors, helped refine the codes, and constant-comparative methods (Corbin & Strauss, 2015) were used to collapse the codes into eight categories. These categories were determined to be characteristics of integrated STEM education and enabled the authors to construct STEM conception profiles for the individual teachers (Miles & Huberman, 1994). Once these eight categories were established, a final pass was made through the PEI data to confirm consistent assignment of the codes and categories both in terms of physical placement and usage.

To account for any discrepancies in the numbers of codes used, frequency counts of these characteristics within the PEI transcript for each participant were calculated using an average count from the two coders, as the disparity in counts was not large. Because the participants' length and depth of discussion varied, percentages of counts were used to better represent the emphasis each participant placed on these characteristics in their description of their conception of STEM integration. These percentages were then translated into levels by binning, using the conversion: $0\% \rightarrow 0$, > 0 to $< 10\% \rightarrow 1$, > 10 to $< 20\% \rightarrow 2$, > 20 to $< 30\% \rightarrow 3$, > 30 to $< 40\% \rightarrow 4$, and > 40 to $100\% \rightarrow 5$. These were then used to create radar charts, visual representations of the teachers' conceptions that aided in the development of the STEM conception profiles. These visual representations, in combination with direct quotes from teachers' PEIs, helped to build an understanding of each teacher's conception of integrated STEM, which we refer to as their STEM conception profiles.

Analysis of the curriculum documents, as opposed to analysis of classroom implementation, was conducted based on the assumption that curriculum documents more accurately reflect how conceptions of integrated STEM were moved into practice without confounding factors, such as classroom management, impacting implementation (van den Akker, 2004). Using the eight characteristics found from analysis of the PEIs, the first and second authors deductively coded the three curriculum unit documents. This coding was done per lesson for each of the eight lessons within a curriculum unit. Similar to the PEI data, radar charts were created for each curriculum unit to visualize the characteristics present in the overall curriculum. The level of use of each characteristic was created in the same fashion as the teacher's conception, which reflects the percentage of use throughout the entire unit.

To understand how the conceptions of STEM integration were transferred from an internal conception to a co-written curricular product, findings from the PEI and curriculum analysis of each case were compared. Within-case analysis was conducted by first comparing the radar charts generated for each team member to determine what characteristics of conceptions overlapped and which did not. The radar chart generated for each curriculum unit was then compared to the STEM conception profiles from each participant in that case to determine areas of overlap and similar patterns. Finally, cross case analysis was conducted to identify similarities and differences between the cases to understand common themes. The focus of this analysis was to determine patterns found across the three cases that might be applicable to other similar cases. This was done by examining across all teachers, across all curriculum units, and across each case as a whole.

Findings

Analysis of the PEI data revealed that teachers conceptualized important characteristics of integrated STEM education as being: (1) *Connecting the disciplines* - the ability of STEM to tie together three or more of the disciplines of science, technology, engineering, and mathematics; (2) *Balance of science and engineering* - equal emphasis on science and engineering in the classroom; (3) *Engineering focus* - centrality of engineering and/or use of the engineering design process; (4) *Engineering as context* - use of engineering to explicitly contextualize student learning of science, mathematics, and/or technology in the classroom; (5) *Science focus* - centrality of the science content and the teachers' jobs in the classroom; (6) *Mathematics and technology as tools/supports in STEM* - the role of mathematics and educational technology in STEM to support classroom pedagogy and student learning; (7) *21st century skills* - emphasis on the development of 21st-century skills such as problem solving, critical thinking, communication, and teamwork; and (8) *Real world connections* - emphasis on making connections to the real world as a way to provide relevancy and student engagement. These eight categories go beyond defining integrated STEM as content, addressing the need for pedagogical aspects to be considered as well. As part of this analysis, it was clear that teachers used the terms STEM and *integrated* STEM interchangeably, suggesting that as practitioners they equate the two. The sections that follow describe how these characteristics were represented in the each of the three cases.

Case 1 - Soccer Stadium

Teacher conceptions

Figure 1 displays a visual representation of the conceptions of integrated STEM held by Josh, Trey, and Keira, each comprised of a unique combination of the eight characteristics. These images show places of overlap, but also areas in which the three teachers differ in their overall conception.

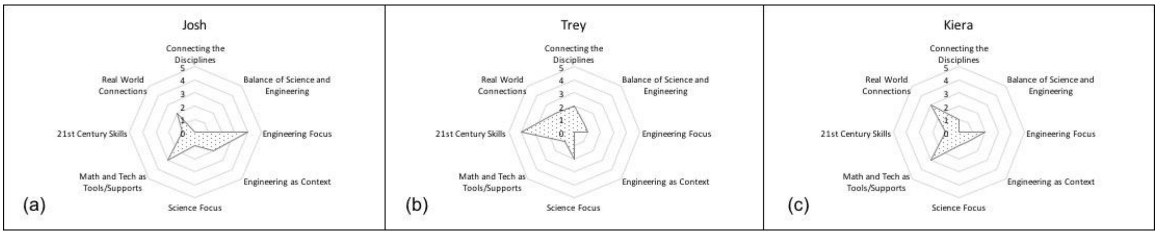

Figure 1. Radar charts of the conceptions of integrated STEM held by the three teachers in Case 1.

Josh, an elementary science specialist, felt that for STEM integration to occur, the engineering design process must be the priority (*Engineering focus).* This dominated his overall conception (Figure 1a). Specifically, he mentioned:

> We start with the problem and then we go through those steps of-we have our problem, we explore it, meaning we learn about it. We kind of do a little research on it. Then we start coming up with ideas to solve the problem. Then after that, we design something off of our idea then we tried it out to make it better and then we redesigned it. We try to go through that cycle.

Engineering as a whole was emphasized in his conception (*Engineering focus*), often contextualizing the science content to give purpose (*Engineering as context*). A second highly present characteristic was Josh's view of STEM as a way to connect to the real world and allow students to develop skills that they might need in their future careers, saying "I do try to talk to kids about that [careers]. This is what people do. This is jobs. This is something they do constantly all the time." Clearly, Josh was concerned about students knowing that STEM was not just for school, which is represented in Figure 1a. Additionally, Josh felt that "... tech is like a tool that helps you research" and described the use of mathematics as "what you're using here" to test a product. This view established the use of mathematics and technology as supports in integrated STEM, such that they helped students find solutions to engineering design challenges, but were not seen as integral content for students to learn in science class.

Trey, the only general classroom teacher in our sample, recognized the need for a focus on science content during science time, but also saw the need to balance science and engineering, remarking, "So, I want to teach them [science and engineering] both ... kind of together, side by side ... however you look at it" (Figure 1b). The most important thing to Trey in bringing STEM to his classroom was the emphasis on developing skills through a 4Cs (creativity, critical thinking, communication, and collaboration) model. Making sure there were connections between the four disciplines was important to him, though he struggled with mathematics in particular, often considering it more of a tool than a large component of STEM integration, stating "There's definitely standards in [the curriculum] ... some math, recording data, and graphing data" (Figure 1b).

Kiera, another elementary science specialist, was very aware of her limited use of technology and mathematics in her conception and implementation of integrated STEM, finding herself prioritizing engineering and the engineering design process (Figure 1c).

> I would think, well, what would be an interesting [engineering] design challenge. Then, after kind of deciding that, I go back to what's the actual science content, where can I put in math? Technology is always just kind of the mystery piece.

In this, she saw integrated STEM as a way to contextualize students' learning of science using an engineering design challenge, which required the engineering design process. She specifically called out technology as a "mystery piece," but it is clear that mathematics was a low priority as well. She recognized that the real-world aspect was a positive way to develop students' skills, but that it offered a somewhat false sense of what the real world is like, making the comment "Kids are not ready for the real world, that's why they're in school."

Curriculum

Soccer Stadium asked students to design and recommend a site for an environmentally friendly soccer stadium using local resources while learning about renewable and nonrenewable resources, how they are processed, and the resultant environmental impacts (Table 2). *Soccer Stadium* included many aspects relating to *21st century skills* – throughout the unit students worked in teams and used critical thinking skills to make decisions and solve problems. Beyond this, the curriculum was framed by lessons that focused on engineering and the engineering design process (Figure 2). In particular, there was an emphasis on STEM as a way to help students understand engineering as a career as well as its role in society. This curriculum was contextualized by an EDC that was presented in Lesson 1 and revisited throughout the unit. The unit presented a distinct and explicit dialogue woven between engineering practices and science concepts. For example, in the second lesson, students were charged with determining the differences between renewable and nonrenewable materials found in the region (**science**); this required students to use engineering practices to conduct tests, which helped determine each material's suitability for its use in construction of the stadium (**engineering**). Though this dialogue was between engineering and science, it often surrounded unrealistic tasks for students, such as ultimately determining where the soccer stadium would be placed. Mathematics and technology were used as tools and supports, as opposed to foci, in this unit. The use of mathematics as a tool could be seen clearly in the second lesson where students explored the various renewable and nonrenewable resources using mathematics and technology as analysis tools for the testing of materials.

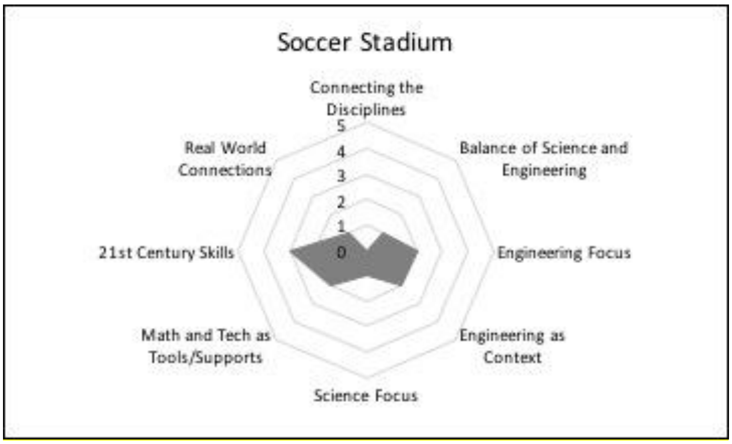

Figure 2. Radar chart of the characteristics of integrated STEM found in the curriculum unit, *Soccer Stadium* (Case 1).

Table 2. *Soccer stadium* lesson summaries and codes assigned during analysis

Lesson	Summary	Characteristics
Lesson 1	Students analyze a letter from a client to understand the Engineering Design Challenge (EDC) and its accompanying criteria and constraints. They create a class concept map and brainstorm the parts of a stadium and the resources required to build it.	Engineering as Context Engineering Focus
Lesson 2	Students gather background information about renewable and nonrenewable materials found in the local region through discussion about the differences, through a station rotation to research different aspects of wood, concrete, and steel as common building materials, and through comparison of the strength of wood, concrete, and steel samples.	Engineering as Context Science Focus Engineering Focus Math/Technology used as tools/supports in STEM 21st Century Skills
Lesson 3	Students examine how forests, sand and gravel, and iron ore are processed into a usable form, supplementing their knowledge with video clips about processing wood, cement, and steel. Students also consider environmental impacts and the relationship between human activity and earth materials.	Science Focus Math/Technology used as tools/supports in STEM
Lesson 4	Students use background information from Lessons 2 and 3 to make a choice regarding the materials they want to use for the stadium's roof, floor, and structure.	Engineering Focus Math/Technology used as tools/supports in STEM 21st Century Skills
Lesson 5	Students work in groups to learn about common renewable energy resources in the region: sunlight (solar power), wind (wind power), and water (hydroelectric power). Students examine how these resources are converted into usable electricity, supplementing their knowledge with video clips about the conversion of solar, wind, and hydropower, and consider the environmental impacts of resource processing. Students create a class Energy Resource Matrix.	Science Focus Math/Technology used as tools/supports in STEM 21st Century Skills
Lesson 6	Students test and compare voltage output of three different models of renewable power generators (a solar panel, a windmill, and a water wheel). Students collect and analyze data that will help inform their decision for the energy source in their stadium design.	Engineering as Context 21st Century Skills
Lesson 7	Students use maps of the region to determine the general availability of the renewable energy sources at three potential stadium sites. They compare seasonal and annual average availability using data tables. Finally, they use evidence-based reasoning to justify their choice for a stadium location and energy source.	Balance of Science and Engineering 21st Century Skills Real-World Connections
Lesson 8	Students bring together everything they have learned about the stadium design challenge to make their design proposal recommendations. They create a product to communicate their recommendations for building materials, energy sources, and a site location. They use evidence-based reasoning while considering the criteria and constraints listed by the client.	Engineering as Context Engineering Focus 21st Century Skills Real-World Connections

Comparison of conceptions and curriculum

In comparing the conceptions of the three authors regarding the curriculum unit itself, it is evident that the ideas of *Engineering as context*, *Mathematics and technology as tools/supports*, and *21st century skills* were transferred from conception to product. Josh's and Kiera's conception of engineering as contextualizing science content learning and Trey's idea that science and engineering should be balanced in the unit were realized in the final curriculum. The presentation of the EDC in the first lesson and its continual revisitation throughout the unit is evidence of the use of engineering as a way to situate science learning. While both science and engineering were represented in most lessons throughout the unit, the connection between the two was clear only in two lessons, thus the low count of the *Balance of science and engineering* characteristic represented in Figure 2. Additionally, Trey's and Kiera's struggles to incorporate mathematics and technology into the curriculum were evident through the near absence of both disciplines in the unit. When mathematics and technology were utilized, it was to help students organize or display data or to make decisions about science content or engineering practices. Josh's and Trey's beliefs that an important aspect of integrated STEM is helping their students develop 21st century skills is also evident in Figure 2. However, Kiera's suggestion that school isn't always "real world" was also evident in the unit as some of the decisions students were asked to make in relation to the EDC were not entirely realistic.

Case 2 - Cross Pollination of GMOs

Teacher conceptions

Figure 3 displays a visual representation of the conceptions of integrated STEM held by Billy, Jean, and Rick.

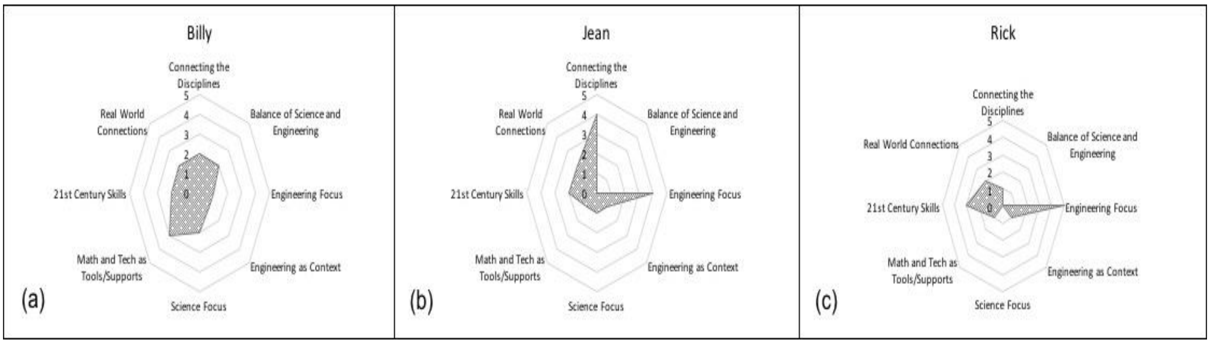

Figure 3. Radar charts of the conceptions of integrated STEM held by the three teachers in Case 2.

Figure 3a shows that Billy, a 6th grade Honors science teacher, believed that integrated STEM involves making connections between the four STEM disciplines, but he described an emphasis on science because "... obviously, my job is to teach the content science standards." Engineering provided a context for that science learning, balancing the two content areas such that "The engineering part is really an awesome venue to teach the content standards while also helping them [students] develop engineering skills." As a teacher who had participated in this project previously, Billy saw these two fields as supporting one another in his classroom where his students experienced high levels of engagement while learning a variety of 21st century skills. Additionally, he saw mathematics and technology as tools used to support science learning, stating "The technology tools and the math analysis are sort of the, I guess, the tools that the kids will have to use to [learn science and engineering concepts and processes] successfully." The visual representation of Billy's conception (Figure 3a) clearly represents these priorities of including both engineering and science to develop 21st century skills, while considering mathematics and technology as only supports or tools.

Jean, a general middle school science teacher, acknowledged the importance of making connections among the STEM disciplines (Figure 3b), although she noted that integrating mathematics into her instruction was challenging and, "... always something we're kind of working on." She prioritized engineering and the engineering design process, explaining her conception of integrated STEM in the following way:

> ... within engineering, you have technology, science, and the math within as a smallest part; but really it just means that, like, it's connected to all of them, you know. So it's just basically kind of ... they're [technology, science, and math] all embedded within the engineering challenge….

Jean noted that STEM integration increased student engagement and provided many opportunities to learn 21st century skills in real-world contexts. She stated, "I just think engineering is so relevant. There's jobs out there in engineering that we don't even know yet and so to get kids thinking like engineers - that's an aspect of being a scientist that we need to do as much as possible." Jean's excitement about the possibilities of engineering being relevant to students was what drove her conception.

Rick, another general middle school science teacher, placed emphasis on the engineering design process (Figure 3c), describing his model as "There's still a process embedded into it, so some way that I can incorporate the science, technology, engineering, math along with this spinning wheel of the process. The design process." The "flow" of the process was most important to him as it provides students with an engaging context in which to learn, which was done through "the incorporation of the client." Rick, who was new to the project, lacked confidence in his understanding of integrated STEM, often clarifying that he was still learning, which he attributed to "being in the very young stages of understanding a true integrated STEM model." He was optimistic about the opportunities to help students make connections to the real world using engineering as a context for their science learning, which was seen as supporting the engineering design process.

Curriculum

Table 3. The *Cross Pollination of GMOs* lesson summaries and codes assigned during analysis

Lesson	Summary	Characteristics
Lesson 1	Students read a client letter asking them to prevent cross pollination of Genetically Modified Organisms (GMOs) and non-GMO crops in farmers' fields. Students learn the basics of GMOs and discuss their relevance in large and small groups. Students read about, discuss, and reflect on the ethics of GMOs.	Engineering as Context Engineering Focus
Lesson 2	Students review cells and the location of genetic material in the nucleus with a group modeling activity. Students complete a DNA extraction lab using strawberries. Students build a DNA model by using origami. Finally, students learn about DNA structure (base pairing) and function through direct instruction.	Science Focus
Lesson 3	Students learn about and discuss genes, alleles, and traits. Students also explore heritable traits by comparing their own traits to those of their parents and their peers.	Science Focus Math/Technology used as tools/supports in STEM 21st Century Skills
Lesson 4	Students learn about reproduction and the processes by which living things inherit genetic material. Students explore inheritance, asexual and sexual reproduction, and plant fertilization through pollination in a stations activity.	Science Focus Engineering as Context
Lesson 5	Students review reproduction and DNA inheritance. Students learn about heredity and the probability of inheritance using Punnett Squares.	Science Focus Engineering as Context
Lesson 6	Students learn about genetic engineering and model genetic splicing and restriction enzymes using a paper plasmid, scissors, and tape. Students complete a pGLO gene splicing lab to reinforce the methods by which genes can be spliced to create a GMO with a trait that was not previously present.	Science Focus Engineering as Context
Lesson 7	Students practice word problems associated with determining appropriate scale factors in various scenarios. Students look at a model of the fields being used in the EDC, measure the length and width of the GMO field and the non GMO field in the model, and determine the area. Students determine the overall scale factor used for the model based on average field size.	Engineering as Context Math/Technology used as tools/supports in STEM Real-World Connections
Lesson 8	Students review the EDC, including the client's criteria and constraints. In teams, students design a scaled prototype of their cross-contamination prevention strategy using the data from their research. Students test, redesign, and retest their prototypes. Students create a presentation of their prototype for their client, which includes justification in the contexts of genetics technologies, heredity, and GMOs.	Engineering as Context Engineering Focus 21st Century Skills

Cross-Pollination of GMOs asked students to design a barrier that effectively prevented the cross-pollination of GMO plants with non-GMO plants in adjoining fields while learning about the scientific concepts associated with genetics and heredity (Table 3). The *Cross-Pollination of GMOs* unit clearly presented engineering as the context in which to learn science content, the primary focus of the majority of the lessons (Figure 4). Students were presented with an EDC in the first lesson through a letter from their client and addressed the challenge in the final lesson. This client letter was used to provide "a context within which to learn the content standards for genetics." However, the vast majority of the material between the first and final lessons focused on science content. The only connection to engineering during these days was in the form of a closure activity in which students were asked to reflect upon how the science content in the lesson related to the client problem. Engineering was mostly used as a way to frame the need for learning the science concepts, but the EDC was not necessarily directly connected to the science content, thus the lack of *Connecting the disciplines* and *Balance of science and engineering* in Figure 4. During this unit, mathematics was used meaningfully only twice. In lesson five, mathematics was used to calculate the probability that an offspring would inherit parental traits in a science lesson disconnected from the EDC, and in the final two lessons scaling was used to help determine the size and cost of the students' prototypes. In this way, mathematics was seen as a tool for helping students analyze science concepts and/or make decisions related to the EDC. Technology was rarely used by students in the unit, but it was suggested in the curriculum unit as an aid to support the teacher in various classroom pedagogies - for example, as a way to gain access to videos and images related to DNA and heredity.

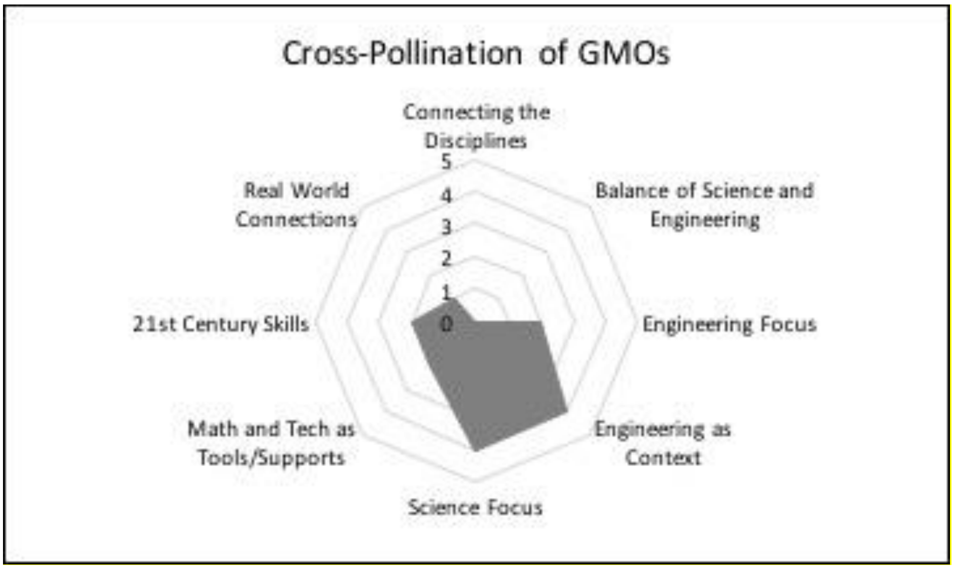

Figure 4. Radar chart of the characteristics of integrated STEM found in the curriculum unit *Cross-Pollination of GMOs* (Case 2).

Comparison of conceptions and curriculum

In considering the overlap of the teachers' conceptions of integrated STEM with the curriculum, *Engineering as context, Science focus,* and *Mathematics and Technology as tools/supports in STEM* were the conceptions most fully reflected in the curriculum, which notably does not include all teammates' conceptions. For instance, both Billy and Jean recognized the importance of using multiple disciplines, and Rick placed an emphasis on design process. Neither of these characteristics was apparent in the curriculum. The client letter introduced at the beginning of the unit framed students' learning of the genetics content by an EDC, a nod toward Billy's conception that STEM utilizes engineering as a context for science content learning. This was also supported by bookending the unit with an EDC that was introduced in lesson one and completed in the final lesson. The obvious emphasis of the unit on science content supports Billy's conception that integrated STEM units in science classrooms should focus primarily on science content. The curriculum lacked much evidence of mathematics and technology, reflecting the conceptions of integrated STEM held by the three teachers, where these were viewed as supportive tools. This can be seen in the loose connection of both mathematics and technology to the science content in the written curriculum. Additionally, while all three teachers felt that teaching *21st century skills* was important, this conception was minimally present within the curriculum.

Case 3 - Improving the Mechanical Claw

Teacher conceptions

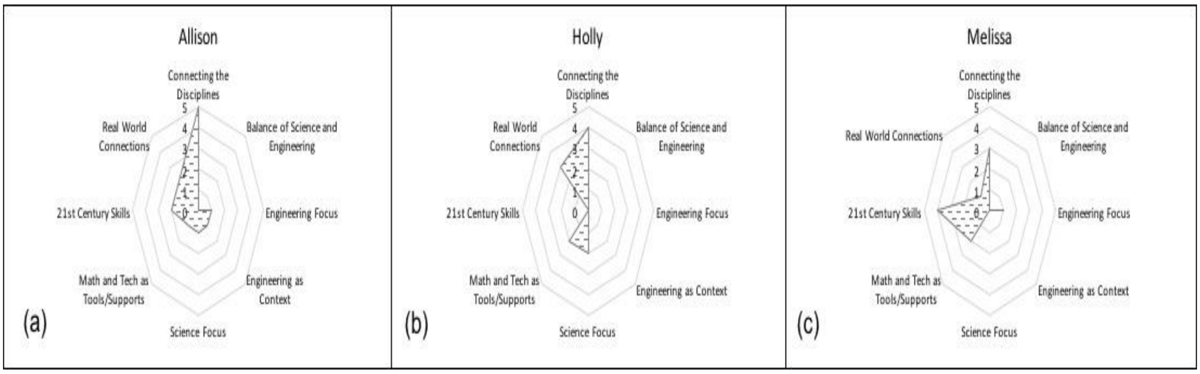

Figure 5. Radar charts of the conceptions of integrated STEM held by the three teachers in Case 3.

Figure 5 displays a visual representation of the conceptions of STEM held by Allison, Holly, and Melissa, which show various areas of overlap and similarities. Figure 5a shows the obvious emphasis that Allison, an elementary science specialist, placed on the requirement of integrated STEM to connect the four disciplines explicitly in some way, shape, or form, including an EDC. She described that "... the different areas of STEM are all connected to each other and they kind of create this bigger picture of what STEM is. So, you can't have STEM without them." She recognized the limitations of the classroom and that mathematics in particular was challenging to incorporate into her conception and her teaching. Allison stated, "You have science and engineering standards together ... and then math, kind of, if you can get it in, it goes in." Allison also felt that STEM integration offered many other connections for students, such as developing real-world and 21st century skills, which overall was good for their development as the future workforce, stating, "I like that STEM does incorporate real world problem-solving, and working in groups, and communicating. That helps students practice real world skills that they're going to need once they leave school even if it's not a standard." Figure 5a reflects the strong emphasis on the connection between the disciplines for students to learn these types of skills.

Holly, also an elementary science specialist, noted that originally she believed integrated STEM should focus on the science content more than anything else, saying, "I am the science teacher, not anything else, so sometimes getting that math incorporated [is difficult]." She stated that she had moved away from this conception, to focus on the connections among the four disciplines (Figure 5b), describing her current conception:

> In the center of [STEM integration], you have an engaging context and in order to reach the engaging context you have to move between math, science, technology, and the engineering design process interchangeably and all these pieces are supposed to be roughly about the same size because each one holds the same amount of importance in order to achieve the overall STEM.

Despite this vision, she recognized her struggle to integrate mathematics and technology into her STEM instruction, "I'm focusing on ways to incorporate math as well as the technology," but overall saw integrated STEM as good for students because of their heightened engagement in instructional activities. As can be seen in Figure 5b, Holly's conception of integrated STEM placed a strong emphasis on connecting the disciplines of science, technology, engineering, and mathematics using mathematics and technology as tools to support the learning of science and engineering. Also an elementary science specialist, Melissa described her conception of STEM as needing the connection of all four disciplines and the inclusion of an EDC (Figure 5c). Though she admitted she struggled to incorporate mathematics and technology, she saw these as important, stating, "I don't think, I mean, you can't have - in my opinion - engineering without science and math." There was an obvious tension between her desire to incorporate these aspects and confidence in her ability to do so. She believed that integrated STEM was more than just a buzzword, such that it required, "redesign, creativity, failing, and teamwork ... because I think you need all of those." Melissa's conception embraced the idea that while integrated STEM required the clear connection and seamless transition between the disciplines, it was more than learning content.

Curriculum

Improving the Mechanical Claw asked students to design an electromagnetic arm as a replacement for typical arcade mechanical claw games while learning about electromagnets and magnetism (Table 4).

Table 4. Improving the mechanical claw lesson summaries and codes assigned during analysis

Lesson	Summary	Characteristics
Lesson 1	Students are introduced to the EDC through analysis of a client letter. Students work with their groups to create group norms that will be used throughout the unit.	Engineering as Context Engineering Focus 21st Century Skills
Lesson 2	Students are given a premade electromagnet to use during structured play time. While exploring the electromagnet, students are asked to think about the different ways you can change it (number of batteries, number of coils, gauge of the wire, type of battery, etc.). Students make a class list of these variables and vote to determine which variable will be tested in the next lesson.	Engineering as Context Science Focus 21st Century Skills
Lesson 3	Students discuss what constitutes a fair experiment, what tools are needed to collect or analyze data, and how the data should be organized. In groups, students test the previously selected variable (number of coils in the electromagnet) and graph their data. Groups develop claims supported by evidence to summarize the findings of their experiment.	Connecting the Disciplines 21st Century Skills Engineering as Context
Lesson 4	Students review the list of variables from Lesson 2 and decide on another variable to test. In groups, students build an electromagnet then test it three times, collecting their data in a data table and then graphing it using Plot.ly. Using Skitch, students annotate their graph showing (1) what they tested and (2) what conclusions they can draw from that data. Students present their data to the class.	Connecting the Disciplines 21st Century Skills Engineering as Context
Lesson 5	Students create a plan for their electromagnet design. They design their electromagnet and test it to see how many washers it can pick up. Students use their data to justify their design decisions and learn about other groups' designs in a Gallery Walk.	Connecting the Disciplines 21st Century Skills Engineering as Context
Lesson 6	Students are introduced to the client's need to determine which materials would work best to be used with the toys that will be found inside the electromagnet arm machine. Students determine which materials are magnetic, first using a permanent magnet and then using their electromagnet.	Engineering as Context Science Focus Math/Technology used as tools/supports in STEM 21st Century Skills
Lesson 7	Students redesign their electromagnet to make it work best with the material they chose (during the previous lesson) for the toy prizes in the game. Students create a video presentation for the client, justifying their designs and any changes they made to it.	Connecting the Disciplines 21st Century Skills Engineering as Context
Lesson 8	Students review electromagnetics, variables, data tables, and graphs and take a post-test on Electricity, Magnetism, Electromagnets, Variables, and basic Engineering Design Processes.	Connecting the Disciplines Math/Technology used as tools/supports in STEM

As can be seen in Figure 6, connecting the disciplines was emphasized in the *Improving the Mechanical Claw* unit. Engineering and science were explicitly interwoven to create a fine balance between the EDC and the science concepts learned in this unit. Additionally, technology was consistently incorporated via various apps to allow students to further their understanding of the science content and show what they learned. Mathematics was often paired with technology via digital graphing tools and was used during decision making and reporting required of the students. An example of this emphasis on the connections of the four disciplines of STEM is illustrated in lesson four. In this lesson students conducted experiments to explore how different variables affect electromagnetic strength (**science)**. During their experiment, students were required to use mathematics to analyze and interpret data (**mathematics**). Students were then given a client memo asking students to report their data back to the client (**engineering**) by "app-smashing" a graphing app called Plot.ly and an annotation app called Skitch (**technology**). The real-world connections established in the unit were strategically designed to engage students through the expansion of the required client letter into regular client memos to the students. This feature went above and beyond the curriculum requirements of the PD and seemed to be a way for the teachers to remind the students of the real-world context of their learning. Throughout the unit, high priority was placed on teamwork, communication, and the use of reasoning to solve problems (*21st century skills*).

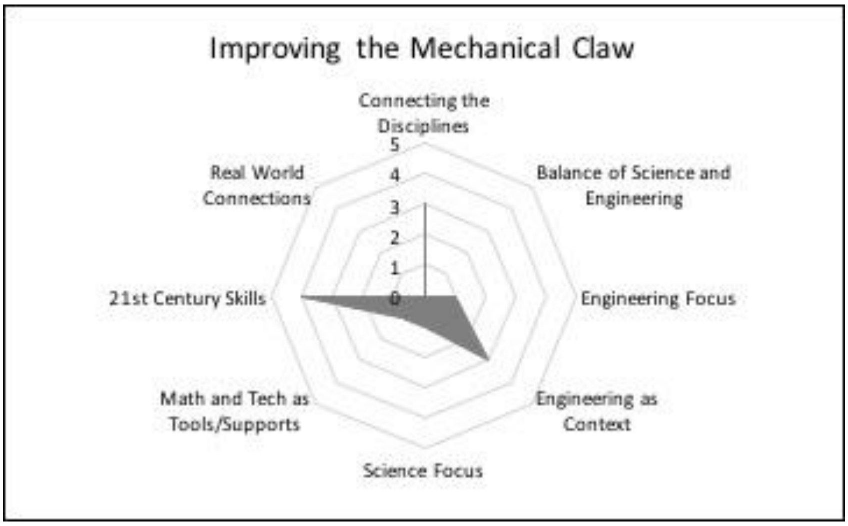

Figure 6. Radar chart of the characteristics of integrated STEM found in the curriculum unit *Improving the Mechanical Claw* (Case 3).

Comparison of conceptions and curriculum

In comparing the three authors' conceptions of integrated STEM to the *Improving the Mechanical Claw* curriculum, it is evident that the ideas of *Connecting the disciplines* and *21st century skills* were mobilized from conception to product by this team. All three of the teachers had described that all four disciplines of STEM should be emphasized in STEM curricula, so it is not surprising that their curricular unit reflected just that. What is surprising is that all three teachers had expressed their concern in making explicit connections to mathematics and technology, but their curriculum made extensive use of both of these areas. These were often used in concert with one another in addition to connections with science and engineering. This was evident in the obvious attention that was paid to weaving the four disciplines together in three of the lessons in the unit.

Cross-Case Analysis

Cross-case analysis revealed several patterns across the cases. These included patterns across the teachers' conceptions and across the curriculum units, as well as general patterns of translation of the teachers' conceptions into the curricula.

Viability of multiple conceptions of STEM

Teachers recognized that their own conception of integrated STEM was influenced by their teaching assignment and even acknowledged that others might have alternative conceptions that were equally valuable. For example, Kiera was aware that integrated STEM might vary in form or definition depending on one's teaching assignment (e.g., science versus mathematics) or the age of their students. Allison was also aware that what STEM integration looks like in practice might change based on teaching assignment, understanding that a science teacher would likely prioritize science content over engineering. In addition, Holly noted that her conception had changed over the course of several years, indicating her belief that conceptions can change over time. It was evident that these teachers understood that their conceptions of integrated STEM are not static - that they are impacted by various factors. In looking across the curricula, the viability of multiple conceptions of integrated STEM is inherent in that the three curricula emphasized different characteristics (Figure 7). While each curriculum was developed as an integrated STEM unit, *Soccer Stadium* placed a high priority on 21st century skills and engineering, *Cross-Pollination of GMOs* emphasized engineering as the context in which to teach science, and *Improving the Mechanical Claw* focused on the use of engineering to contextualize the learning of 21st century skills.

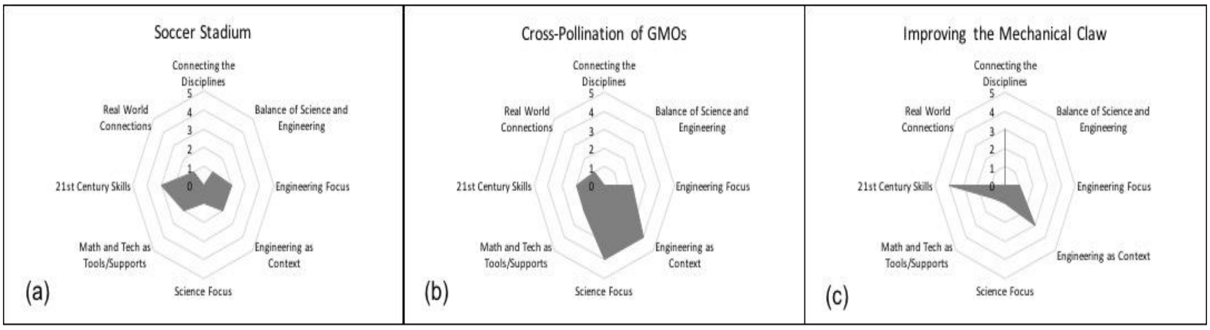

Figure 7. Radar charts of the three curriculum units found in Cases 1-3.

Tensions with technology and mathematics

Analysis of the PEIs revealed that technology and mathematics were often viewed as supports or tools to either (1) help students understand science concepts or (2) make decisions about EDCs. It was evident that teachers found it less important to teach new mathematics content or utilize technology meaningfully in their integrated STEM units than it was to use these disciplines as aids in supporting learning of science content or in addressing the engineering design challenge. This resulted in mathematics being used in the curricula as a tool for data analysis and measurement related to science or engineering activities. Simultaneously, some teachers recognized the importance of using mathematics and technology and, as in the case of Melissa, attributed their discomfort with teaching mathematics as contributing to their hesitancy in teaching new mathematics content. Similarly, technology was not used often innovatively in the curricula, but as a way to replace direct instruction and introduce science content, most often through video clips (Tables 2, 3, and 4). The exception of this occurred when all three teachers on the curriculum writing team strongly believed in the necessity for explicit connection between the disciplines, which happened in only one case (Case 3). This particular conception of integrated STEM, held by all three team members in Case 3, appears to have led to a curriculum that fully embraced all four disciplines of STEM despite the teachers' shared discomfort in incorporating mathematics and technology.

Relationships between characteristics of Integrated STEM

Cross-case analysis of the PEIs and curricular units revealed that relationships existed among the eight characteristics of integrated STEM. Teachers who identified science as being most important to them because their primary job was that of science teacher (*Science focus)* often utilized engineering or the engineering design process as a way to contextualize the learning of science content in their classrooms (*Engineering as context*). This can be seen in both Billy's and Josh's conceptions of STEM, as well as the curricula they developed. Billy, whose view of integrated STEM was highly science focused, felt that using engineering as a context was a good way to engage his students in the learning of science content. Similarly, Josh felt that science content could be incorporated most authentically in his classroom through his use of the EDP. It was also evident that connecting the disciplines tended to be acknowledged as an ideal way of implementing integrated STEM; however, enacting this conception in the written curricula was evidenced in only one curriculum unit (Case 3 - *Improving the Mechanical Claw*).

It is evident that the units all presented a science focus, which is not surprising given that the intention was for these units to be used in science classrooms (Figure 7). Although the science focus in the *Cross-Pollination of GMOs* (Case 2) was more apparent than the other two units, it was still present in both *Soccer Stadium* (Case 1) and *Improving the Mechanical Claw* (Case 3). There is also evidence that the three units used engineering as a way to contextualize the science content. For example, a client letter explaining the engineering design challenge for the unit was described at the beginning of all three units. This letter was revisited throughout the units' lessons, reminding students of their tasks. This also provided evidence that the requirements of the professional development (i.e., the inclusion of a client letter) impacted the teachers' writing of the curricula.

Engineering as context and *Real-world connections* occupied separate yet overlapping positions in both the teachers' conceptions and the curricula. The teachers emphasized the importance of connecting content to the real world in their individual conceptions (*Real-world connections*). When translating this characteristic into a written curriculum, it appears to have taken the form of the required client letter, which was used to contextualize student learning in an EDC. In Cases 1 and 2, the curricula also included other opportunities to engage students in making real-world connections (i.e., practice problems that presented real-world problems for content learning). However, despite these other opportunities, real-world connections were most often represented in the written curricula by the use of a client letter and the EDC to contextualize student learning (*Engineering as context*).

21st century skills and/or *Real-world connections* tended to occupy a prominent position in teachers' conceptions of integrated STEM and, taken together, these two frequently dominated the teachers' conceptions. This may have been because *21st century skills* and *Real-world connections* seemed to be compatible with each of the other six characteristics of integrated STEM as they were seen as supplemental to content instruction, providing avenues to incorporate good pedagogical practices. This idea was often highlighted when teachers considered the impacts of integrated STEM on student learning in their classrooms and their motivation for teaching integrating STEM. For example, Josh, Jean, and Allison felt that teaching integrated STEM was an excellent way to prepare students for the workforce by teaching them 21st century skills (critical thinking, problem-solving, teamwork, and communication). Rick and Kiera felt integrated STEM was a way to engage students through the use of real-world contexts. In the three curricula, applying the content of the unit to real-life situations (often within the context of the EDC) and to the students' lives (outside of the school day) was emphasized. For example, students were asked frequently to reflect on how the content of the lessons they were learning applied to the real-world problem presented in the EDC.

Translating conceptions into written curricula

In looking across the three cases, generally the characteristics identified as important to integrated STEM in the conceptions of the teams of three teachers were aligned to the characteristics present in their curriculum units. This likely was due to the fact that the individual team members had similar general conceptions due to their shared experiences in the summer professional development. However, some conceptions of individual team members were better aligned than others. For instance, Alison, Holly, and Melissa (Case 3) shared the dominant conception that integrated STEM required the explicit connection among the STEM disciplines; their curriculum exemplified this extremely well. Individual conceptions of integrated STEM held by the teachers in Case 1 and Case 2 were similar, but less aligned than the conceptions of the teachers in Case 3. In Case 1, there were noticeable differences between the teachers' conceptions regarding the discipline that should be most emphasized in the unit - engineering or science. This resulted in a unit that tended to emphasize both disciplines, but the explicit connections between science and engineering were missing within the lessons. In Case 2, Rick emphasized the engineering design process, while both Billy and Jean noted the importance of making connections between disciplines. However, the final curriculum unit appears to best represent Billy's conception of integrated STEM compared to either Jean's or Rick's, as the unit is highly focused on science content, contextualized by an EDC as opposed to focusing on the centrality of engineering or the engineering design process.

Discussion and Limitations

Eight characteristics were recognized as being important components of integrated STEM education to these teachers: (1) *Connecting the disciplines*; (2) *Balance of science and engineering*; (3) *Engineering focus*; (4) *Engineering as context*; (5) *Science focus*; (6) *Mathematics and technology as tools/supports in STEM*; (7) *21st century skills;* and (8) *Real-world connections*. In addition to these eight characteristics, several of the teachers suggested in their PEIs that there are limitations to integrating STEM in the classroom. These limitations were defined as time (both to plan and the amount of time to implement) and money. Because these limitations are not unique to STEM integration and tend to be limitations for all teachers, this was not reflected in the eight components listed above. However, this is an area of STEM integration that lends itself to further research, especially regarding how integrated STEM curricula are implemented in the classroom.

Each team of teachers in this study held unique and complex understandings of integrated STEM, and these conceptions were reflected in the curricula they developed. Individually, the teachers tended to have conceptions driven by one (or more) of the eight characteristics above. These primary characteristics, whether content-driven or pedagogically-driven, guided the overall conceptions of the individuals. It is clear that some teachers highly valued the engineering components (e.g., Josh) or science content (e.g., Billy), others the need to explicitly connect between all disciplines represented by the STEM acronym (e.g., all members of Case 3), and still others who viewed integrated STEM as a new form of pedagogy to teach students skills (e.g., Todd). This complexity in teachers' conceptions reflects the variety of definitions of integrated STEM found in the literature (Breiner et al., 2012; Bybee, 2013; Moore et al., 2014a;). Despite this, teachers acknowledged that their own conception was not *the* only conception of integrated STEM. This resulted in the teams needing to negotiate conceptions if differences existed. This negotiation resulted in curricula that were amalgamations of the teachers' individual conceptions. The less aligned the teams of teachers' conceptions were (Case 1 and Case 2), the less the teachers' individual conceptions were representative of their individual voices in the curriculum.

In addition to the teachers' conceptions, evidence also existed of the influence of the professional development in the written curricula. This is in alignment with findings in all three of the units, as an EDC was presented at the beginning of the unit and typically completed in the last lesson. This reflects the professional development's guiding STEM integration framework and its emphasis on the use of a client letter to introduce an EDC and provide a motivating and engaging context (Moore et al., 2014a; Moore et al., 2014b). The client letter also served as a means for teachers to make real-world connections for their students. Additionally, the curricular units emphasized the process of design and the ideas of teamwork and communication that are central to the professional development's quality K-12 engineering education framework (Moore et al., 2014b). The content-specific breakout groups during the professional development (e.g., physical science, earth science, life science) also may have impacted the teachers' conceptions as there was some variation in the time spent emphasizing different components of and pedagogies related to integrating STEM in the classroom.

Several other factors may have impacted not only the individual teachers' conceptions, but their curricula. The first is the amount of experience the teachers had in the professional development. For example, in Case 2 it is possible that Billy's experience in the project (3 years) caused Jean (1 year) and Rick (1 year) to default to him in the curriculum writing process, causing the curriculum to better reflect Billy's conception of integrated STEM. This may reflect a certain level of confidence that teachers about their own conception of integrated STEM. The second factor is that the science content for which the curricula were written may have led to differences in the teams' abilities to integrate all four STEM disciplines. While physical science seemed to lend itself well to the incorporation of an EDC and the integration of STEM (Case 3), earth science (Case 1) and life science (Case 2) seemed to be more challenging in this regard. A larger study looking at more curricula from these disciplines would be necessary to understand this more fully, but others have made the case that physical science lends itself better to the inclusion of engineering (Moore et al., 2014b; Guzey, Moore, & Harwell, 2016; Wang et al., 2011).

Implications

In a constant effort to improve science and integrated STEM education, this work will help administrators, teacher educators, and educational researchers understand the needs of K-12 teachers who are expected to teach integrated STEM. This study expands and elaborates upon previous work (Ring et al., 2017) to better understand the complexity of teacher conceptions of STEM integration and how they are represented in integrated STEM curricula. We found that teachers equated the terms STEM and integrated STEM, likely related to their position as practitioners who are constantly thinking about their practice. Our findings suggest that different conceptual models of integrated STEM held by teachers lead to different ways of creating, developing, and writing integrated STEM curricula. While the process of developing the curricula was not examined in this study, our findings indicate that teacher conceptions of integrated STEM play a significant role in what they decide to include and emphasize in units they create. This supports the body of literature suggesting that how teachers conceptualize content, as well as how and when content should be taught, influences curriculum development (Brown, 2003; Cheung, 2000, van Driel et al., 2008). This is important to understand when administrators and state-level evaluators think about what integrated STEM curricula look like when conceptualized, written, and implemented.

One of the key pieces to this study was the fact that, as part of the grant-funded project, all teacher participants were expected to have certain components in their curricula. How those components are emphasized, though, is how the teachers were able to actualize *their* conceptions of integrated STEM education, working as a team to do so. If teachers are expected to work in teams, similar to those described here, there must be an understanding by all that integrated STEM may not mean the same thing from person to person. Negotiations of personal conceptions must take place before being able to talk coherently with others about their conceptions. The ability to negotiate these conceptions appeared to play a role in the overall design and representation of integrated STEM within the team-created units, which may additionally play a role in the quality of the units. While these findings do not necessarily translate directly to classroom practice, they do indicate that the way teachers conceptualize integrated STEM is evident in their curriculum development. Further study is needed as to how these conceptions are enacted in the classroom, as it is possible that the individual conceptions may be more apparent in individual practice compared to a co-written curriculum.

Additionally, it is possible that the eight conceptions identified by Ring et al. (2017) and the eight characteristics of integrated STEM identified in this paper may exist on a continuum from conceptions and characteristics of STEM that result in less effective integration of the STEM disciplines to more effective integration. This may have contributed to the complexity of teachers' conceptions of integrated STEM, where certain characteristics that might seem to contradict one another could actually coexist (e.g., seeing the importance of mathematics and technology for integration, but only using them as tools or supports). While there was evidence of this in this study, it was not the focus of the study and further analysis of the data must be conducted to determine the validity of this claim. If this is the case, it would be important for researchers, administrators, and practitioners to consider these continua to meet the goals of integrating STEM in K-12 education.

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