Elementary Teachers' Use of Engineering Curriculum Materials (Fundamental)

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Integrating Science and Engineering Curriculum in Elementary Classrooms

Engineering is one of the pillars of STEM education, and is an explicit focus in the Next Generation Science Standards (NGSS)[1]. The NGSS includes eight science and engineering practices central to both disciplines and extremely significant to student investigations. Engineering is also included as a key theme in the NGSS's Disciplinary Core Ideas, thus ensuring students and teachers in many K-12 classrooms across the US will be engaged with engineering education. The framework upon which the NGSS is based states, "Students should learn how science is used, in particular through the engineering design process, and they should come to appreciate the distinctions and relationships between engineering, technology, and the applications of science"[2]. Science and engineering complement each other in many ways, but teach students different, yet equally important, skill sets. "If the core of science is discovery, then the essence of engineering is creation"[3]. The challenge of including engineering in school programs is evident[4], especially at the elementary level where time dedicated to science instruction is far less than that dedicated to reading and math[5]. The challenge of integrating science and engineering, therefore, is an added layer of complexity, due to both these time constraints and because engineering practices and curriculum are new to most elementary teachers. There is no existing research on the integration of science and engineering curriculum, including whether teaching engineering and science separately or simultaneously is more effective.

Elementary teachers are trained as generalists and are required to teach all subjects to their students. Therefore, they take a few courses in each discipline rather than specializing in a particular area. They typically have very limited preparation in science, as most teacher preparation programs require only 2-3 science courses for certification at the elementary level. The recent focus on engineering poses additional

challenges for elementary teachers as it is very rare for a teacher preparation program to require (or even offer) engineering courses for their preservice teachers. It is noteworthy that the authors' institution offers an engineering course for preservice elementary teachers. In our teacher preparation program, we have seen a strong demand for this type of course as it fills quickly and often has a wait list for enrollment.

Even more challenging for elementary teachers is the fact that there is little engineering curriculum for the elementary grades available yet. Those that do exist are (1) relatively new to the market, and (2) typically not integrated with science or other curricula, notwithstanding the interdisciplinary nature of engineering. In most cases the disciplines in STEM are still taught as independent silos, despite increasing calls for integrated STEM curriculum. It is this vexing problem of how to integrate the STEM disciplines that we focus on in the present study. Integration of the STEM disciplines could occur in a variety of ways. Bryan, Moore, Johnson and Roehrig[6] present three possible scenarios (content, supporting content, and context integration):

> Content integration refers to units and activities that have multiple STEM (and potentially other) disciplinary learning objectives; whereas supporting content integration refers to units and activities in which one content area is meaningfully covered (e.g. mathematics) in support of the main content's learning objectives (e.g. science). Context integration uses a context from one discipline to situate learning objectives from another discipline.

No curriculum yet exists that integrates all aspects of STEM. Teachers and districts still have the job of combining different science, technology, engineering, and math curriculum together in hopes of integrating the disciplines in a meaningful way. With the most recent release of the NGSS in 2013, much effort is being put into the development of curricula aligned with the 3-dimensions of the NGSS: disciplinary core ideas, science and engineering practices, and crosscutting concepts[1]. Even if

developed tomorrow, it would still take years for most districts to adopt and implement this new curriculum in elementary classrooms. Curriculum adoption and revision requires many levels of professional development, pilot study implementation, and district/board approval. In the meantime, teachers are left to work with the curriculum they currently have and attempt to meet the demands of the NGSS.

Research has shown that, given their limited preparation for teaching science, elementary teachers rely heavily on their science curriculum materials[7, 8]. This reliance stems from a combination of factors including (1) teachers' reported low self-efficacy for teaching science[9], (2) their reported lack of deep content knowledge in science[10], and (3) the de-emphasis of science in elementary schools in favor of reading and math[5]. This reliance also leads to elementary science curriculum being taught with a high level of fidelity[11, 12]. While teaching curriculum with high fidelity may be a goal of curriculum developers, it likely does not meet the needs of diverse learners. Teachers should be encouraged to modify and adapt existing curriculum to meet the needs of their own learners and teaching styles[13]. It would seem logical to conclude that since elementary teachers are even less prepared to teach engineering through their teacher preparation, reliance on engineering curriculum would also exist. However, no research has investigated elementary teachers' use of engineering curriculum materials. Our hypothesis is that there is a trade-off between teaching science and engineering curriculum materials with fidelity and modifying them to be integrated as STEM curricula.

This project explored the ways in which elementary classroom teachers integrated science and engineering in their classrooms while piloting new curriculum units. This paper will present findings associated the implementation aspects of a larger study that examined how elementary teachers *incorporated* engineering into their science classes, and how they *integrated* engineering into their science lessons.

Specifically, the questions that guided this study were:

1. In what ways do elementary teachers integrate engineering and science?

    a. What science content do they integrate into engineering units?

    b. What adaptations do they make to the engineering curricula?

    c. What factors influence teachers' choices for making these adaptations?

Methods

This exploratory case study examined the ways in which teachers implemented an engineering curriculum in their classroom. The study occurred in a large, urban school district in the beginning stages of a STEM initiative with future plans to open a middle-level STEAM Academy (STEM + Art). The initial step in this vision was the adoption and piloting of new science (Science and Technology Concepts [STC] and Full Option Science System [FOSS]) and engineering (Engineering is Elementary [EiE]) units in grades 1-6, in two of its eight elementary schools. All teachers in the two participating elementary schools received targeted professional development on their new science and engineering units (Table 1) and taught the units between January and May. All professional development was contracted from one provider (not the authors of this study). This organization also provided all curriculum materials to the district. One of the authors attended the professional development sessions as an observer. Instructional materials for the units were then shipped to the district on a pre-set schedule and returned when instruction was completed.

Table 1. *Science and Engineering curriculum units implemented across grades 1-6.*

Grade	Engineering is Elementary Unit	Science Unit
1	The Best of Bugs: Designing Hand Pollinators	STC Organisms
2	A Sticky Situation: Designing Walls	STC Soils
3	Water, Water, Everywhere: Designing Water Filters	FOSS Water
4	An Alarming Idea: Designing Alarm Circuits	STC Circuits
5	A Slick Solution: Cleaning an Oil Spill	FOSS Environments
6	Marvelous Machines: Making Work Easier	STC Motion and Design

In order to represent a maximum variation cross-section of grade levels, building principals at the two pilot schools helped in the selection of six purposefully chosen teachers (see table 2) who volunteered to participate (a type of convenience sampling[14]) in the case studies. Teachers who had shown an interest in attempting STEM ideas in their classrooms were the aim of the selection criteria.

Table 2. *Study participants.*

Teacher Name (pseudonym)	Grade	School (pseudonym)
Kim	1	Brentwood Elementary
Sharon	3	Brentwood Elementary
Melissa	4	Brentwood Elementary

Amy	4	Maple Place Elementary
Lance	6	Maple Place Elementary
Jeremy	6	Maple Place Elementary

The primary data sources that informed this project were: (1) video-recorded EiE lessons, (2) the written curriculum units, and (3) semi-structured interviews with the teachers. The six participating teachers video-recorded their EiE lessons using an iPad. The videos (n=31) averaged 34 minutes in length and captured the implementation of EiE curriculum. We chose to focus on the EiE lessons as data because they were taught after the science units per the materials arrangement through the district. It was our hope that we would capture teachers incorporating their previously taught science content into the engineering units. The semi-structured interviews[14] were conducted to investigate what was "in and on the minds" of the teachers[15] and elicit examples of how the teachers incorporated engineering practices into their lessons. Interviews focused on the lessons video-recorded by the teachers and their ideas about engineering, science, and integration.

The videos and interviews provided the research team with a rich data set to begin to explain if and how the teachers integrated science content and engineering design, how they implemented the engineering unit, and what adaptations they made to the curriculum. The data was analyzed using V-Note (https://v-note.org) for video-recordings and transcriptions of interviews. Cases were built by triangulating the data for each participating teacher[14]. Open coding and an inductive approach[14, 15] to data analysis were necessary for this exploratory research. The six teachers provided multiple case comparisons[14] within and across grade levels and began to build a

comprehensive story of how teachers incorporated and integrated science and engineering content.

Findings

Analysis of the videotaped EiE lessons revealed that very little science content was integrated into the EiE unit across the participants and a continuum of adaptation emerged across participants. In addition, there was little/no explicit representation of the NGSS practices of science and engineering or attention to crosscutting concepts between science and engineering. We categorized these findings into three areas that emerged: (a) factors beyond classroom and teacher control, (b) within classroom teacher decision-making,. Within these areas, the challenges associated with integration are explored. Finally, findings about how the teachers adapted the engineering curriculum and the factors influencing those decisions are discussed.

Lack of Integration of Science & Engineering

Before presenting the results, we feel it is meaningful to define what we mean by *integration*. While there are many possibilities for integrating science and engineering, for this exploratory study we focused on the integration of science content and science practices into engineering lessons. For example, in an engineering challenge about building hand pollinators, we might expect to see science content such as pollination, insect parts, plant physiology, etc. included in the engineering lessons. We might also see science practices such as asking questions, collecting data, making claims through argumentation, etc. (i.e., NGSS practices) integrated into the engineering lessons. Even though this may seem like a narrow definition of integration, we attempted to find any and every time the teachers integrated science content and/or practices into the engineering lessons.

Factors beyond teacher control. Many of the barriers to integrating science and

engineering were the result of things over which the participating teachers had no control. These included (a) district choice of units, (b) professional development model, and (c) kit rental logistics. These administrative-level logistics influenced the opportunities teachers had to integrate science and engineering. First, the degree of concept alignment between the STC/FOSS unit content and EiE curriculum content seemed to be one factor that influenced whether the teachers integrated the science and engineering units. In some instances, the science concepts were not closely aligned with the core concepts in the engineering unit. This mismatch was unexpected because as an aid to adopting their engineering curriculum units, EiE suggests specific pairings between their engineering units and popularly published science curriculum. Specifically, they identify concept aligned units across GEMS, FOSS, STC, Insights, and Science Companion (http://www.eie.org/eie-curriculum/eie-connects-standards).

In our study, the units that were implemented with the most integration (STC *Electric Circuits* and EiE *Designing Alarm Circuits*) were also the most closely aligned and recommended by EiE for use together. In contrast, the STC *Motion and Design* was not recommended for use with the EiE *Making Work Easier* unit. These curricular choices were made by the school district and the teachers in this study did not have any influence over these decisions. As a result, differences in integration emerged between the well-matched units and those less suited for each other. The well-matched units (STC *Electric Circuits* and EiE *Designing Alarm Circuits)* resulted in more opportunities for integration than the units where the content was not aligned. For example, both units included designing circuits and teachers were able build on students' prior experience to design more challenging circuits to solve the problem. *Making Work Easier* (EiE) involves simple machines, whereas *Motion and Design* teaches about force and motion. EiE suggested either FOSS *Levers and Pulleys*, Insights *Lifting Heavy Things*, Science Companion *Energy*, or STC *Balance and Weighing*.

Second, even though the units were purposely paired to support the STEM education initiative by the district, the science and EiE professional development occurred separately and months apart. In addition, the teachers received one day of science professional development and one day of engineering professional development. Even though the same organization (and in most instances the *same* instructors) provided the professional development, most of it was devoted to logistics of how to teach the particular unit, rather than the theoretical underpinnings of the curriculum and the practices of science and engineering. Also surprising, given the instructors had provided the professional development for science, there was no emphasis on building connections or integration across the science and engineering units.

Finally, the timing and logistics of the physical materials for teaching each unit did not support the teachers' integration of the science and engineering concepts or practices, because implementation occurred independently, during different times of the school year. The science units were taught in January- March, and the EiE units followed during April-May. This schedule was not at the discretion of the teachers. Because the district arranged for and scheduled the delivery of the units, there was not an opportunity to teach them concurrently. One of the grade levels experienced a delay in the shipping of their live insect specimen because of the extremely cold winter temperatures in the northeast. Due to this delay in shipping, teachers to had to push back even further in the school year the engineering unit until after the science unit was completed.

These three factors beyond the teachers' control, (a) district choice of units, (b) professional development model, and (c) kit rental logistics, impacted the opportunities for integration of science and engineering curriculum. These barriers to integration could have been overcome at the district level.

Within Classroom Teacher Decision-making. While the overall lack of integration between science and engineering is not surprising given the restraints of the implementation, unit alignment, and lack of professional development on integration. However, in the instances of strong concept overlap opportunities for integration still emerged. For example, in every EiE unit the third lesson is characterized by EiE in the following way, "Students collect and analyze the scientific data they'll need to inform their designs in Lesson 4" (http://www.eie.org/eie-curriculum/eie-lesson-plan-structure). The content for this lesson differs for each unit, but the structure of lesson three is the same across all units. Lesson 3 activities are designed to demonstrate how information learned through scientific experimentation can inform the development of solutions during the engineering design process, thereby giving teachers an opportunity to integrate science and engineering.

In this study, the EiE unit, "An Alarming Idea: Designing Alarm Circuits" EiE's intended goal for lesson 3 was: "Students perform controlled experiments to identify conductors and insulators, and students practice drawing schematic diagrams" (http://www.eie.org/eie-curriculum/curriculum-units/alarming-idea-designing-alarm-circuits). In several instances, we found these opportunities for connections between content and practices were not utilized to the fullest extent. For example, when Melissa taught this unit she did not reference the students' explorations as scientific, instead explaining that what they were doing was going through the engineering design process. For example, after handing out the materials she explained to the students: "Follow the engineering design process. This [referring to schematic diagram protected on screen] is your, this almost is like your planning, now you're going to ask each other questions. You're going to build it, improve on it, if it doesn't work troubleshoot, OK? So I want to see everything laid out" (Lesson 3 12:15). A few minutes later, after noticing students making modifications to the circuits they are building, she pauses their work to remind them, "You need to follow the schematic diagram, to a T, OK?" Melissa's choice

about how to conduct this lesson could be viewed as both a valuable adaptation for her students, who already had experience building circuits (discussed more below) and as a missed opportunity to demonstrate the relationship between science and engineering, as well as a mischaracterization of the engineering design process. This is not surprising however, given their limited experience and professional development in engineering.

In contrast, Sharon omitted many of the discussion items in the EiE *Designing Water Filters* curriculum, most notably the prompts that made direct connections to the science unit. For example, the teacher guide states:

> Guide students to think about the relationship between science and engineering. Ask: How is the testing that you did today similar to a science experiment?... [possible student responses] How is it different?... [[possible student responses] Why do you think several groups tested the same type of contaminated water?... [possible student responses]".

This prompt is an example of a connecting the science content with the engineering lesson. Sharon explained her omission of certain prompts as an issue of time and simply needed to move on with the unit. While time is certainly often a concern and constraint in classrooms, it was interesting that her omission also limited her opportunity to build connections between her students' science and engineering learning experiences.

Adaptations to engineering curriculum

When examining the ways in which the teachers implemented the EiE units, a continuum of fidelity emerged across the teachers. Some of the teachers taught the curriculum verbatim (almost as a script). Others adapted the curriculum for a variety of reasons. Some of the adaptations were implemented to meet the needs of their

students, to match their own teaching style, or to challenge their upper-elementary students who they felt could handle more complexity than the curriculum presented.

Melissa and Lance are on the two ends of the continuum, with Sharon being somewhere in the middle. Of all the participating teachers, Lance most closely followed the printed EiE curriculum teacher's manual. He taught the unit verbatim from the curriculum guide, without making any substitutions or adaptations. Lance is seen at multiple points in his videos referring directly to the teacher pages in the EiE curriculum materials and,in many instances, he reads the questions straight off the page. We characterized his teaching practice as an example of fidelity to the curriculum. His representations of engineering were exactly as written by the curriculum. It is important to note that Lance's science and engineering units were not well aligned conceptually (Motion and Design vs. Marvelous Machines), so his lack of explicit references to science is not unexpected.

In contrast, Melissa made many adaptations to her engineering unit and her two units were conceptually aligned as both were about circuits. Her adaptations included the addition of lesson components to enhance student's experience and increase exposure to engineering ideas, as well as modifying lessons to be more challenging and to better meet the needs of her students. When discussing her planning, Melissa said she was "super excited" to teach the EiE unit and, "I watched several YouTube videos that demonstrated the design process for the lesson. I also used the EiE manual, online learning tools, and several teacher blogs and sites" (Pre-teaching Interview). While she felt the content of the EiE and science units integrated perfectly, she admitted that she added teaching elements such as video clips and flip charts, and adapted the flow of the lessons to best suit her learners and her teaching style. In lesson 3, where opportunities for science connections are most explicit, Melissa modified the lessons to more closely align with her students' abilities. For example, rather than building simple circuits with a

battery, bulb and wire, Melissa gave each group of students different sets of materials that enabled them to build more complex and challenging parallel circuits. Her students applied what they did in their science unit, rather than just repeating it in the engineering unit.

Like Melissa, Sharon's science and engineering units were also well aligned (Water/Designing Water Filters). However, her instructional goals and preparation for teaching the engineering was somewhat different. Sharon admitted she was nervous about preparing all the materials and "getting all the information to the students" and to prepare for teaching engineering, she "read through the manual" (Pre-teaching Interview). While there was overlap between the EiE *Designing Water Filters* unit and a segment of the FOSS Water unit that investigated water filters, Sharon did not feel changes were necessary to the lessons and had no intention of integrating the science and EiE units. As a result, her adaptations included removing the sections of the EiE unit that referenced science connections and presented opportunities for integration. Rather than building connections between science and engineering, Sharon planned "to integrate the science curriculum in with our reading program" (Pre-teaching Interview).

Discussion and Implications

This study has implications for teacher education, professional development providers, district administrators, curriculum developers, and eventually (and importantly) classroom practice. While this study includes a small sample size of teachers, it is a first step in understanding how teachers begin to *incorporate* engineering design into their existing curriculum, and how they *integrate* science and engineering content.

Many of the barriers to integration occurred at levels over which the teachers had no control. District administration and professional development providers should

address these factors in order to allow more opportunities for integration of the disciplines of science and engineering. For example, the order that the instructional materials are delivered to the teachers does not always have to be science first and engineering second. If the teachers were able to have the kits at the same time, they would have more choice of which lessons occurred in what sequence. More research is needed on different models of integration between science and engineering curriculum. What might happen if engineering is taught before science content, for example?

Importantly, district administration should be paying attention to which kits they adopt for science and engineering. In this district's case, a misalignment between the sixth grade science and engineering units caused very few chances for teachers to reinforce one unit with the other because their content was completely different. EiE has gone to great lengths to recommend which science unit (across multiple publishers) would best suit each of their units, and districts should be making these decisions purposefully. In cases when both the science and engineering kits are not being adopted at the same time (as was the case in this study), existing curricula should be considered as to what new curriculum would align most closely. This basic issue of unit alignment deserves further research, as it is a first line of opportunities for integration between disciplines.

There is also a need for strong professional development on how to align and integrate the STEM disciplines. In most cases, professional development emphasizes one of the disciplines rather than how to integrate them together, as was the case in this study. Some researchers claim that "it can take three to six years before teachers are genuinely comfortable engaging in engineering practices with their students"[16]. Teachers need strong examples of how to integrate their curriculum, practice doing so in a supportive environment, and tools for making modifications successful for their own classroom of learners. In addition professional development providers should model

integration between units and inform teachers about how their curriculum could be integrated with other disciplines in multiple ways.

When thinking about integrating science and engineering curriculum, there seems to be a trade-off between teaching curricula with a high degree of fidelity and making adaptations to the curriculum materials to teach STEM in an integrated fashion. We only focused on two of the disciplines in this study (science and engineering) and found there was relatively little integration between these two. If all four disciplines were investigated for integration, it would get much more complicated. Since the curriculum materials themselves did not model integration opportunities, adaptations would be necessary in order to integrate across disciplines. This finding has implications for districts as they select curricula or try to align existing curriculum units for STEM integration and also for curriculum developers who could include ideas within their materials for teachers that demonstrate opportunities for integration with other disciplines.

Additionally, we see a need to broaden the definition of fidelity. When we looked at fidelity to curriculum in a step-by-step fashion (how closely a teacher followed the specific procedures of the curriculum manual) Melissa's fidelity was considered low. However, considering how teachers implemented the objectives and goals of the curriculum without worrying about the specific details of each procedure, Melissa's fidelity was much stronger. While she made adaptations to her curriculum, we argue she still taught it with fidelity. Her adaptations made the lessons more challenging for her upper-elementary students and did not repeat what they had learned in their science unit. Overall, we argue that teachers need this freedom and flexibility in order to integrate their existing curricula in meaningful ways.

Finally, this study has caused us to question the goals of integrating STEM disciplines in the classroom. While we argue on the surface that integrating the four

disciplines seems like a worthwhile endeavor, the layers of complexity that it adds on teachers who have to adapt their curriculum materials in order to provide their own opportunities for integration might not be worth the trade-off in the end. In this study we explored how two of the STEM disciplines were integrated in elementary classrooms, and we saw very little evidence that the integration was occurring. Imagining how complicated it would be for teachers to integrate math and technology seems even more daunting. Research that explores how to support teachers who choose to integrate STEM subjects, and whether integration is truly beneficial, is needed.

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