Examination of Integrated STEM Curricula as a Means Toward Quality K-12 Engineering Education (Research to Practice)

Mr. Aran W Glancy, University of Minnesota, Twin Cities

Aran W. Glancy is a Ph.D. Candidate in STEM Education with an emphasis in Mathematics Education at the University of Minnesota. He is a former high school mathematics and physics teacher, and he has experience both using and teaching a variety of educational technologies. His research interests include mathematical modeling, computational thinking, and STEM integration. Specifically, he is interested in the ways in which integrating engineering or computer science into mathematics and science classes can support and enhance learning within and across the STEM disciplines.

Dr. Tamara J Moore, Purdue University

Tamara J. Moore, Ph.D. is an Associate Professor of Engineering Education at Purdue University. Dr. Moore's research is centered on the integration of STEM concepts in K-12 and higher education mathematics, science, and engineering classrooms in order to help students make connections among the STEM disciplines and achieve deep understanding. Her research agenda focuses on defining STEM integration and investigating its power for student learning. She is creating and testing innovative, interdisciplinary curricular approaches that engage students in developing models of real world problems and their solutions. Her research also involves working with educators to shift their expectations and instructional practice to facilitate effective STEM integration. Tamara is the recipient of a 2012 Presidential Early Career Award for Scientists and Engineers (PECASE) for her work on STEM integration with underrepresented minority and underprivileged urban K-12 students.

Dr. Siddika Selcen Guzey, University of Minnesota, Twin Cities

Dr. Guzey is a Research Associate at the STEM Education Center at the University of Minnesota. Her research and teaching focus on integrated STEM education.

Mrs. Corey A Mathis, Purdue University

Corey A. Mathis earned her B.S. in biology and her M.E.D. in secondary education from Northern Arizona University. Prior to returning to school to obtain a PhD in engineering education at Purdue University, Corey spent nine years as a 7-12 grade Arizona science teacher. While at Purdue she has developed a course for Engineering Technology Pathways in addition to bring statistic to science classrooms though teacher outreach programs.

Kristina Maruyama Tank, University of Minnesota, Twin Cities
Emilie A. Siverling, Purdue University

Emilie A. Siverling is a Ph.D. Student in Engineering Education at Purdue University. She received a B.S. in Materials Science and Engineering from the University of Wisconsin-Madison, and she is a former high school chemistry and physics teacher. Her research interests are in K-12 STEM integration, primarily using engineering design to support secondary science curricula and instruction.

Examination of Integrated STEM Curricula as a Means Toward Quality K-12 Engineering Education (Research-to-Practice)

Strand: K-12 Engineering Resources: Best Practices in Curriculum Design

For some time now, educators and policy makers have been focused on improving both education and career preparedness in the fields of science, mathematics, engineering, and technology (STEM). This push has been multifaceted, and it is having a variety of impacts on education policy and practice. One particularly significant result is the increased focus on engineering education in K-12 settings. National documents have called for an increase in both the quality and quantity of engineering at the K-12 level[1-3], and the infusion of engineering into the Next Generation Science Standards[4] has firmly established engineering as a core component of a K-12 education for all students. Furthermore, much work has been done to begin to frame the core ideas essential in a quality K-12 engineering education[1-2,5]. Despite this progress, however, educators and policy makers have not yet determined how best to teach engineering and in what space (i.e. within science/mathematics, as a standalone subject, or in integrated settings) to teach it.

At the same time, many argue that integration of the STEM disciplines has great potential. Furner and Kumar[6] argue that integrated approaches help to connect the disciplines and increase the relevance of the material to the students. Roehrig, Wang, Moore, and Park [7] found that integrated STEM teaching encourages student-centered pedagogies, and Stohlmann, Moore, and Roehrig [8] found that integrated lessons allow for a more authentic treatment of mathematics and science content. Morrison[9] found integrated STEM education promotes innovation, higher order thinking skills, and technological literacy. Brophy, Klein, Portsmore, and Rogers[10] argue that engineering education specifically supports a wide range of STEM learning objectives. Others argue that integrating the STEM disciplines through engineering has the potential to improve students' knowledge and perceptions of engineering as a profession as well as encourage more students to pursue STEM related careers[2,11]. Thus, it seems that within the K-12 setting, engineering might be best addressed within integrated STEM classrooms.

Realizing the promises listed above of integrated efforts in the classroom, however, will require at a minimum adequate professional development, institutional structures that support integration, and quality integrated curricula around which teachers can develop their instruction. Each of these in turn will require significant research and development as best practices are developed and refined. In this paper we focus on the third in that list: integrated curricula. Combining content from multiple disciplines in a meaningful way is no easy task, and it is important to ensure that the essential aspects of each of the different content areas are not lost through the process of integration. With that in mind, in this study we examine the engineering content in 10 curricular units developed for use in science classrooms to teach science and engineering content through engineering design challenges. These curricula were developed by practicing science teachers who were attempting to add engineering and mathematics content to their middle school science courses. Specifically, we were guided by the research question: *In what ways do integrated science and engineering curricular units address (or fail to address) the important aspects of K-12 engineering education?*

STEM Integration Through Engineering

In order to discuss the merits of the engineering within integrated STEM units, we must first establish what qualifies as integrated STEM curricula. As Brophy et al.[10] argue, curricula centered around engineering design challenges offer students meaningful ways to engage with mathematics and science content, implying that engineering is a natural conduit for STEM integration. In *Engineering in K-12: Understanding the Status and Improving the Prospects,* the NRC[2] examined several engineering curricula for K-12 students and identified the important themes in engineering education that appeared within the curricula, but this analysis did not examine the mathematics or science content of the different units. Subsequent research has shown that at least in some cases, K-12 engineering curricula do not necessarily enhance mathematics and science learning[12,13]. Thus, simply having students engage in engineering design challenges does not, in and of itself, result in quality integrated STEM curricula.

Moore, Stohlmann, Wang, Tank, Glancy, & Roehrig [14] proposed a model of STEM integration centered on engineering design that attempts to identify the components of integrated curricular that can capitalize on engineering to enhance learning in multiple disciplines. The authors first identify two types of integration: context integration, and content integration. If the disciplines are integrated through context, then one discipline is the focus of learning, while the additional disciplines provide the setting, or context, for the problem. In these situations, the integration is meant to reveal connections between the disciplines and make the tasks more meaningful for the students, but the curricula does not seek to directly address any learning objectives from the secondary disciplines. Many of the curricula examined in *Engineering in K-12: Understanding the Status and Improving the Prospects*[2] fall under this category. These curricula focus on engineering while using the other disciplines as context, which may explain why they were not necessarily successful in increasing mathematics and science learning. Content integration, on the other hand, is when the curricular units explicitly contain learning objectives from multiple STEM disciplines. To achieve true content integration, Moore et al.[14] argue that curricula must contain five essential elements. According to this framework, curricula must (1) be based on a *motivating and engaging context*, (2) contain *meaningful and important mathematics and science content,* (3) employ *student-centered pedagogies,* (4) engage students in an *engineering design task,* and (5) emphasize *teamwork and communication*. Curricula that successfully address each of these five components are poised to reap the benefits described above of an integrated STEM education. The curricula reviewed in this paper were all designed with these five components in mind.

Components of Quality K-12 Engineering Education

The disciplines of mathematics and science have well established, if not always well agreed upon, standards for what constitutes a quality K-12 education. These come in the form of standards documents such as the Common Core State Standards for Mathematics[15] and the Next Generation Science Standards[4], but within K-12 engineering education, the core components are not established nearly as well. In order to assess the engineering content within integrated STEM units, we must first establish our criteria for a quality K-12 engineering education. For this analysis we use the *Framework for Quality K-12 Engineering Education*[5]. This framework consists of 12 *key indicators* that mark the essential elements of a K-12 engineering education. The indicators and a brief explanation of each are included in Table 1. (For a more complete discussion of the framework and its development see Moore et al.[5]). These indicators are meant to be addressed multiple times and at multiple levels throughout a students' K-12 experience, and a student whose education has been structured in such a way should be prepared to pursue further study in engineering or engineering related careers.

Table 1
A Framework for Quality K-12 Engineering Education[5]

Key Indicator	Description
Process of Design (POD)	Design processes are at the center of engineering practice. Solving engineering problems is an iterative process involving preparing, planning and evaluating the solution.
Problem and Background (POD-PB)	Identification or formulation of engineering problems and research and learning activities necessary to gain background knowledge
Plan and Implement (POD-PI)	Brainstorming, developing multiple solutions, judging the relative importance of constraints and the creation of a prototype, model or other product
Test and Evaluate (POD-TE)	Generating testable hypotheses and designing experiments to gather data that should be used to evaluate the prototype or solution, and to use this feedback in redesign
Apply Science, Engineering, and Mathematics Knowledge (SEM)	The practice of engineering requires the application of science, mathematics, and engineering knowledge and engineering education at the K-12 level should emphasize this interdisciplinary nature
Engineering Thinking (EThink)	Students should be independent and reflective thinkers capable of seeking out new knowledge and learning from failure when problems within engineering contexts arise.
Conceptions of Engineers & Engineering (CEE)	K-12 students not only need to participate in an engineering process, but understand what an engineer does.
Engineering Tools & Processes (ETool)	Students studying engineering need to become familiar and proficient in the processes, techniques, skills, and tools engineers use in their work.
Issues Solutions & Impacts (ISI)	To solve complex and multidisciplinary problems, students need to be able to understand the impact of their solutions on current issues and vice versa.
Ethics	Students should consider ethical situations inherent in the practice of engineering.
Teamwork (Team)	In K-12 engineering education, it is important to develop students' abilities to participate as a contributing team member.
Engineering Communication (Comm-Engr)	Communication is the ability of a student to effectively take in information and to relay understandings to others in an engineering context.

The *Framework for Quality K-12 Engineering Education* is consistent with the principles of engineering education outlined in other national documents, and in some sense is an effort to synthesize those principles. The report *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* identified three principles for the focus of K-12 engineering education: (1) emphasis on engineering design; (2) incorporation of important and developmentally appropriate mathematics, science, and technology knowledge and skills; and (3) promotion of engineering habits of mind such as systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations. The report *A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas*[3] upon which the Next Generation Science Standards[4] were based, lists engineering as a disciplinary core idea and emphasizes engineering design as well as the relationships between science and engineering practices. All of these principles and ideas are contained with the *Framework for Quality K-12 Engineering Education*, but this framework organizes them in a succinct way, gives structure to engineering processes of design, and makes things such as conceptions of engineers and engineering, and engineering-specific communication explicit. For these reasons the framework as described in Table 1 is an ideal formulation of K-12 engineering concepts for use in the analysis of integrated STEM curricula.

Methodology

This study examines the engineering content of 10 integrated STEM units developed by teams of middle school science teachers for use their classrooms. The analysis is qualitative in nature, seeking to provide a rich description of the ways in which different units address the important aspects of engineering.

EngrTEAMS Project. The 10 integrated units analyzed in the paper were developed as part of the *EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Team-Based Targeted Mathematics-Science Partnership* project[16]. The purpose of this project is to support middle school science teachers through professional develop and cognitive coaching in developing and implementing effective integrated STEM curricula. During a three-week summer professional development workshop, teachers are trained in engineering content as well as effective, constructivist pedagogy, inquiry, and design-based instruction. During this workshop teachers are presented with both the *Framework for Quality K-12 Engineering Education* as well as the framework for STEM integration described above. As part of this professional development, participating teachers also experience several model integrated units. The three-week session concludes with a curriculum-writing workshop where small groups of teachers develop a unit to be implemented with their students during the next school year.

The curricula that the teachers develop go through at least three iterations following a design-based curriculum development[17]. The first and second iterations conclude with an implementation, which in turn leads to revisions and the next iteration. The first implementation comes in the form of a pilot with middle school aged children during a STEM summer camp, and the second implementation is during the following school year in the teachers' respective science or STEM classes. During the development and implementation process, teachers are paired with curriculum and pedagogical coaches who work with the teachers and their teams in both the development, implementation, evaluation, and revision of the units. In total, during the first year of the *EngrTEAMS Project*, 22 groups worked on curriculum development and are currently (as of the time of this writing) somewhere between iterations one and two. The 10 units chosen for this study were the ones that were furthest along in that development at the time when analysis began.

Data Analysis. The data for this study consisted of the written curriculum documents of the 10 units chosen from the first cohort of *EngrTEAMS Project* teacher groups as described above. We performed content analysis[18] on these documents. Each curriculum document was coded for the presence of the 12 key indicators in the *Framework for Quality K-12 Engineering Education* (Table 1). Additionally, when the presence of an indicator was identified, we ranked the degree to which the lesson met the indicator with a score ranging from 1 to 4 indicating *weakly present*, *adequate, good,* and *excellent*. Prior to coding the units in this study, we used this process to code a published middle school engineering unit. Each author coded the unit individually, and we then compared codes and resolved any differences through discussions. Notes from this discussion served as benchmarks both for what counted as the presence of an indicator as well as a rubric for scoring the codes. The unit of analysis within each unit was the lesson. Each lesson was considered independently for the purposes of coding.

We then used these codes and scores to organize, compare, and aggregate the engineering content across units. Using the codes to identify places where each indicator was met and the degree to which it was met, we looked across the units, referring back to the original documents for patterns and themes. For each key indicator we then summarized the emergent themes. We did not perform any quantitative analysis of the codes or scores; these codes were simply used to help formulate the descriptions that follow in the results and discussion section and were not intended to be evaluative of the units themselves.

Results and Discussion

The following descriptions of the ways in which the integrated STEM units addressed the key indicators contain examples from many of the units. As such, we begin by providing a short description of each unit in order to give the reader some context as to the nature of the units both in general and individually. The units covered a variety of science content in the areas of life science, earth science, and physical science, and each unit was designed for and aligned with the science curriculum in a specific classroom between grades 4 and 8. All of the units included some sort of engineering design challenge, and each of the units addressed standards associated with data analysis and measurement. Some units included other topics in mathematics, but a discussion of that is beyond the scope of this paper.

Integrated STEM Units

Space Plants (Life Science)
In this unit, students are asked to engineer a container that can allow astronauts to transport and grow a plant from seed while traveling from Earth to their destination (1 month traveling time)

so the plant can be partially developed upon arrival. Throughout the unit students learn about the life cycle of a plant and the role that plants play within an ecosystem.

The Disappearing Moose (Life Science)
The moose is one of the largest land mammals on Earth, however in Minnesota's healthiest moose habitats, there has been a 65% decline in moose population since 2008. Although many factors contribute to this problem, growing numbers of reports are showing that ticks may be a big contributor to the decline. In this unit, students learn about a "tick-ti-cide" that effectively kills ticks. The challenge is to design a delivery system for the tick repellent that delivers it to the highest percentage of moose over a wide area of Northern Minnesota.

Loon Nesting Platforms (Life Science)
In this unit, students learn about ecology and ecosystems through the construction of loon nesting platforms. The loon is the state bird of Minnesota. Students find a good location for their platform based on characteristics of the loon habitat and the dietary needs of loons. After incorporating food chains and food webs, students make an educated decision as to where to place their platform. Students then explore predator/prey relationships during the construction and redesign of their nesting platform.

Pollutants in the Pond/Lake ecosystem (Life Science)
This unit focuses on a local golf course that has been using too much fertilizer causing the lake ecosystem to become unhealthy and out of balance. Throughout the unit, students attain background knowledge about a pond/lake food web and the interdependence of these organisms, the damage that phosphorus in fertilizer can cause on an aquatic ecosystem, and the history of a local body of water. Students record observations at a nearby pond/lake, collect and examine water samples and identify organisms found in the area. Students ultimately design a barrier or other means of stopping or slowing fertilizer from running off into a model pond/lake.

Human Impact on Mississippi River Recreational Area Design (Earth Science)
In this unit, students receive a memo from Ms. Harriet, Mississippi River Fossil Foundation local president. Ms. Harriet, has outlined the criteria for an outdoor functional area to be designed by local community members. The land needs to promote outdoor recreational area, such as fishing piers, overnight camping, and increase usage by local residents while at the same time preserving the parks natural attractions and ecosystem. It is important to Ms. Harriet to keep the Mississippi River's natural features preserved for future park visitors. Ms. Harriet has a grant of up to $600,000 that design engineers will budget for the preservation and utilization of the local area. Ms. Harriet has asked students to create a land-use proposal that will convince Ms. Harriet, her committee board, and other potential investors to use your preservation design as the Mississippi River's newest park highlights.

Solar Ovens (Physical Science)
In this unit, students learn about conduction, convection, and radiation through inquiry based labs and guided instruction. Students also revisit previous topics learned such as changes of energy forms, the electromagnetic spectrum, and reflection of light. Students use knowledge of science concepts to build a thermos and a solar oven.

Rocket Powered Delivery SySTEM (Physical Science)
Zip lines have become popular activities for adventurers. First used in China as a transportation method between mountain villages, zip lines can now be found at many vacation spots including amusement parks. In this unit, students design a rocket-powered delivery sySTEM to move a single rider from a starting position to an ending point at Valley Fair amusement park where customers have been complaining that it takes too long to walk from the exit for Power Tower to the line for Steel Venom. Valley Fair has already strung a 130 foot wire cable from a platform at one ride to a platform at the other. Typically zip lines use gravity to move riders from the start to finish of the zip line, but Valley Fair has installed a horizontal line so students need to come up with a rocket-powered delivery system. A rocket-powered zip line will not only make lines more efficient, but it will also be a great marketing tool for Valley Fair!

Water desalination-Survivor Style (Physical Science)
Clean drinkable water is a necessity for life on this planet. Although the entire earth is surrounded by water, only 3% is fresh water. In this unit, students are challenged with the task of developing and building a portable filtration and desalination device that purifies “dirty”, salty water and makes the water safe for drinking. Using multiple labs and activities, students explore the physical properties of matter including phases of matter and solubility.

Ecuadorian Fishermen (Year 1 and Year 2) (Physical Science)
A group that works with small businesses in Ecuador has discovered that some of the Ecuadorian fishermen need help. These fishermen take their small boats over to the easternmost Galapagos Island (San Cristobal), which has many unusual and tasty fish. They need to bring ice with them in a cooler that will stay cold long enough to bring the fish back unspoiled. Once back to their fish markets in Ecuador, the fishermen need a small cooker to cook the fish in so they can be sold for the greatest profit. This curriculum is planned to take place over two years. The first year culminates with the design of the cooler, and the second year culminates with the design of the cooker. Both of these units focus on the science of heat transfer.

Engineering in the Integrated Units

Although each unit had strengths and weaknesses with regard to the engineering content, we did find that most of the indicators were addressed at least at some point during the unit. Table 2 displays which indicators were present in each of the units. The process of design indicators (POD, POD-PB, POD-PI, POD-TE), engineering tools and processes (ETool), teamwork (Team), and engineering communication (Comm-Engr) were well represented appearing in nearly every unit. Note that POD was only coded when lessons either directly discussed the steps in a complete process of design or if students engaged in all phases of a design cycle within one lesson. The physical science units for the most part broke the design process up over several lessons, so no single lesson received a code of POD. Not surprisingly for these units, which were designed to be delivered in science classes, students were also given opportunities to apply mathematics and science (SEM) in every unit. Other indicators were not represented as well, with only four units addressing issues, solutions, and impacts (ISI) and conceptions of engineers and engineering (CEE) and only three units addressing engineering habits of mind (EThink). Only one unit contained any ethical considerations in a meaningful way.

Table 2
Summary of the Presence of Each Indicator within the Integrated Units. Check marks indicate that evidence of that indicator was found at least once within the unit.

Integrated Unit	POD	POD-PB	POD-PI	POD-TE	SEM	EThink	CEE	ETool	ISI	Ethics	Team	Comm-Engr
Life Sciene												
Space Plants	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔
Loon Nesting Platform	✔	✔	✔	✔	✔		✔	✔	✔		✔	✔
The Disappearing Moose	✔	✔	✔	✔	✔	✔					✔	
Pollutants in the Pond/Lake Ecosystem	✔	✔	✔	✔	✔		✔	✔	✔		✔	✔
Earth Science												
Human Impact on River Recreational Area Design	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Physical Science												
Solar Ovens		✔	✔	✔	✔			✔			✔	✔
Rocket Powered Delivery SySTEM		✔	✔	✔	✔						✔	✔
Water Desalination: Survivor Style		✔	✔	✔	✔			✔	✔		✔	✔
Ecuadorian Fisherman (Year 1)	✔	✔	✔	✔	✔			✔			✔	✔
Ecuadorian Fisherman (Year 2)		✔	✔	✔	✔							✔

Key Indicators within the Integrated Units

We now summarize the ways in which the units addressed (or failed to address) each of the indicators individually.

Process of Design (POD): Engineering design is a central tenant of engineering practices and a crucial component of engineering activities. The curriculum analyses showed that each unit includes an engineering problem that students solve through applying engineering design processes. While engineering design challenges are integrated into all the units, the engineering design processes are described in different forms in each unit. For example, in the life science units certain characteristics of an engineering design process are presented in one lesson, which usually takes place at the beginning of the unit. Students then apply each sub-indicator (POD-PB, POD-PI, and POD-TE) in separate lessons later in the unit. The *Loon Nesting Platforms* unit is a specific example where the engineering challenge and engineering design processes are introduced during the first day of the unit. After students learn about the engineering design process, they explore necessary science and mathematics concepts as part of their engineering design. Students start with identifying the problem (POD-PB), which is to design a floating platform on the water for loons. Students then develop a plan (POD-PI) and test and evaluate their solutions (POD-TE). In four of the five physical science units on the other hand, teachers introduce the engineering challenge early or later in the unit, however, the units do not explicitly present an engineering design process in a single lesson. Rather students are introduced to the engineering challenge (e.g., designing a way to cook food using sunlight) (POD-PB) in one lesson, they are asked to design a solution (e.g., a solar oven) (POD-PI) in another lesson, and finally they are asked to design, redesign, and evaluate (POD-TE) their solutions in the final lesson of the unit.

Apply Science, Engineering, and Mathematics Knowledge (SEM): Application of science and mathematics in engineering challenges is a critical component of quality K-12 engineering education. Students should have the opportunity to apply developmentally appropriate science and mathematics concepts when they solve engineering challenges. Without science and mathematics connections, engineering activities become isolated, unrelated activities. In all 10 units, students study mathematics or science concepts through engineering design processes. However, the degree of science or mathematics knowledge for students needed to solve the engineering challenges varies in each unit. For example, particularly in the life science units, students are introduced to a level of science content which goes beyond that which is essential for solving the engineering challenge. In the *Pollutants in the Pond/Lake Ecosystem unit*, students are asked to design a barrier to stop or slow fertilizers from running off into a model pond/lake. This unit covers all science standards and benchmarks about ecosystems appropriate for 5th grade students, not just the content directly applicable in the design challenge. Students complete a variety of activities such as dissecting an owl pellet to see evidence of food web, using dichotomous keys to identify river organisms, and testing water samples for phosphorous levels. In units such as this, connecting each science activity back to the engineering context is critical in maintaining the coherence and integration of the units. In other units, especially in physical science, the science content is in some ways more conducive to age appropriate engineering design challenges, thus the content within the unit was more tightly focused on the content that was directly applicable to the design challenge.

Engineering Thinking (EThink): Engineers are independent thinkers who not only seek knowledge to help solve a problem but also understand that failure can lead to better solutions. To think like an engineer, students must use systems thinking, be creative and innovative, and learn from their mistakes. The EThink indicator was present in three of the 10 units, but it was only weakly addressed in these three. It was completely absent from the others. EThink was clearly not a focus within the units. For example, the *Space Plant* unit attempted to show students that there are multiple ways to solving a problem by allowing teams of students to take a variety of measurements and then share their results and technique with the class. From there students were asked to consider all the possibilities they had been presented with to identify the technique they felt should be used in the design project. Similar reflections were used in two other lessons within this unit. The *Mississippi Park* unit began the first lesson with the failure of a design and in each of the following lessons students investigated several ways to solve the problem. In this case systems thinking and learning from experience were present within the lesson, however only implicitly. Although these examples do provide evidence of the EThink indicator, they only minimally address it. To more adequately address this indicator, units would need to more directly focus on it while also giving students the opportunity to use and develop these habits of mind, not just learn about them in the abstract.

Conceptions of Engineers and Engineering (CEE): Overall, the CEE indicator was only minimally addressed in the curriculum assessed for this study. Although four out of 10 of the curricula reviewed did cover conceptions of engineers and engineering at some point during the unit, even in the curricula that did hit the CEE indicator, they only did so in one or two lessons, and it was never a major focus of the lesson.

Two of the units that addressed CEE did so as part of their engineering design challenge. The contexts of the units put the students in the role of engineer, and when their task was introduced, a point was made to address the role of engineers in general and more specifically for the task at hand. For example, the *Space Plants* unit included the following teacher instructions as part of the introductory activity for the engineering design challenge lesson:

> *Provide the students with some background information on what an engineer is and what engineering is.*
>
> *a. Have them write the definitions in their notebooks*
>
> *b. Have them discuss with their partners examples of engineers in the real world.*

Although this short discussion does not dive very deeply into the content of the CEE indicator, it does at least provide an introduction upon which future lessons and discussions could be built.

Another approach to addressing this indicator came in the form of bringing in a guest speaker to talk to the students about the work that he or she does. Putting a human face on an engineer and giving the students a chance to hear first hand and ask questions may help to demystify the profession while also clearing up some misconceptions about engineers and engineering.

Engineering Tools and Processes (ETool): Being able to use the processes, techniques, and tools is an important part of engineering. Of the 10 units, seven addressed ETool at least once during the unit. Six addressed this indicator during the design challenge lessons and one unit addressed it in other lessons. These often focused on tools such as thermometers or rules to measure the effectiveness of their prototype. For example, the *Water Desalination* unit required students to use tools such as electronic balances, flasks, hot plates, graduated cylinders and salinity probes to measure changes in salinity in both open and closed systems. The salinity probes are then used to measure how “dirty” the water is. Almost by definition, hands-on activities put the tools in the hands of the children, thus making this indicator a fairly natural one to address through engineering integration.

Issues Solutions and Impacts (ISI): The ISI indicator was not properly addressed in all curriculum units. Four of the eleven curriculum units use a context that addresses contemporary issues such as water pollution. Students learn about these issues, develop possible solutions, and explore possible societal and environmental impacts. For example, in the *Water Desalination* unit, students are asked to design and build a portable and reliable desalination device. Access to safe drinking water is a global issue. 780 million people across the world lack access to clean water and 340 million people die each year due to the water related issues. These facts are an explicitly part of the unit. It is critical, both in general and specifically for this assignment within the unit, for students to understand issues and problems related to unclean water and possible solutions to these problems. Developing cost effective solutions could reduce diseases related to unclean water and could increase economic growth in developing countries. Realistic problems such as the design of a water desalination tool allow students to become aware of realistic problems that exist outside of school. On the other hand, problems whose contexts would seem to relate to important issues or be impacted by solutions (such as the *Disappearing Moose,* or the *Ecuadorian Fishermen*) did not satisfy the indicator, despite their contexts. Just because a unit is related to important issues, impacts, or solutions does not mean that it will automatically satisfy the ISI indicator. Curriculum designers must make sure that these components of the problem are made explicit.

Ethics: Ethical considerations are important to consider in engineering as all decisions have consequences. Overall this indicator was not addressed with the one exception of the *Mississippi Park* unit, which weakly addressed ethics in one of the seven lessons. In one lesson students were asked to examine how humans' choices to improve their lives have impacted the environment in a variety of regions. These discoveries are then applied to the development of their park design. Though the lesson does refer to considerations and consequences it does not directly state ethics as being the focus, thus the importance of ethical considerations could be easily lost on the students.

Teamwork (Team): Building teamwork skills is a critical part of K-12 engineering education. The activities in all the integrated units require students to participate in collaborative groups to design and test engineering solutions. However, the level of teamwork within each curriculum unit is different. For example, in the *Mississippi Park* unit students participate in team activities throughout the whole unit. While some of these teamwork activities involve only think-pair-shares, others require students to work in cooperative learning groups. In the *Mississippi Park* unit, students start with a think-pair-share but then the teacher has the students break up into groups. Each group is responsible for researching a topic (answering very specific questions) and then they create a poster. Students present the information (and poster) to the class.

Engineering Communication (Comm-Engr): K-12 engineering education should allow students to learn about communicating their engineering ideas and solutions. This indicator was addressed well in all but one unit, and even in that unit we felt that engineering communication was implied if not explicitly stated. Typically, students present their engineering solutions to the class to explain their design or the process that they have gone through. Whole class discussions allow students to see other design solutions and help them in redesigning their engineering solutions. Other common examples of engineering communication occur when students are asked to write reports that contain written language, drawings, plans, and budget. In general, the reports are written to the "imaginary" client (e.g. biologists at Department of Natural Resources) to explain their procedure and how it meets the needs of the client.

Implications and Conclusions

As discussed above, engineering and engineering design challenges show great promise as a means for integrating the STEM disciplines, but as this analysis shows, centering a unit on an engineering design task does not guarantee that it will meaningfully address all the important aspects of K-12 engineering education. Clearly, adding design tasks will naturally provide a meaningful way of engaging students in the engineering processes of design, and the hands on activities that typically accompany them provide a fertile ground for developing knowledge of engineering tools and processes, teamwork, and communication skills. And integrating engineering into science classes provides students with ample opportunity to apply their knowledge of science and mathematics.

Not all aspects of a quality engineering education are so easily and naturally addressed, however. For example, even when important engineering issues or the impacts of engineering solutions are embedded within the context of a unit, students will only have the opportunity to engage with them if they are made explicit. As another example, consider that despite the fact that there is almost always some ethical component to an engineering design challenge, only one unit gave students the chance to grapple with those ethical issues. Furthermore, the important aspects of engineering education extend beyond the process of design, and this analysis shows that even with a central engineering design task these aspects are not always met. Curriculum developers must consider ways to supplement the engineering design challenges in order to adequately address things like engineering thinking and conceptions of engineers and engineering.

As Stohlmann et al.[8] point out, enthusiasm for STEM integration and the development of engineering and other integrated materials has in some ways outpaced research in the field. Integrated curricular materials and integrated approaches do provide many opportunities for improved outcomes, but we must continue to critically examine these products to ensure that they are living up to their potential. This study examined, the engineering content within integrated units, but similar studies are needed to examine the science, technology, and mathematics content as well as. Furthermore, the implementation of integrated curricula creates a whole new set of challenges for the disciplinary specific teachers attempting to implement them, and developing the supports that these teachers need is another important task that lies ahead. The curriculum units analyzed here were developed by practicing teachers with little experience in curriculum development, and they are still in the early stages of development. Yet these units addressed many important aspects of engineering in meaningful and creative ways. As researchers continue to learn what does and does not work in these integrated spaces, there is no doubt that the prospects for this type of work will continue to improve.

Acknowledgment

This material is based on work supported by the National Science Foundation under grant numbers NSF DUE-1238140. Any opinions, findings, and conclusions or recommendations are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

1. National Academy of Engineering. (2010). *Standards for K-12 Engineering Education?* Washington, D.C.: The National Academies Press.
2. National Research Council. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. (L. Katehi, G. Pearson, & M. Feder, Eds.). Washington, D.C.: National Academies Press.
3. National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.
4. NGSS Lead States. (2013). Next generation science standards: For states, by states. Washington, DC: The National Academies Press.
5. Moore, T.J., Glancy, A.W., Tank, K.M., Kersten, J.A., Stohlmann, M.S., & Smith, K.A. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of Precollege Engineering Education Research.*

6. Furner, J. M., & Kumar, D. D. (2007). The mathmatics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science and Technology Education*, *3*(3), 185–189.
7. Roehrig, G. H., Wang, H., Moore, T. J., & Park, M. S. (2012). Is adding the "E" enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44.
8. Stohlmann, M., Moore, T., & Roehrig, G. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28–34.
9. Morrison, J. S. (2006). Attributes of STEM education: The student, the academy, the classroom. *TIES STEM Education Monograph Series*, (August).
10. Brophy, S., Klein, S. S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387.
11. National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: The National Academies Press.
12. Stohlmann, M. S., Moore, T. J., McClelland, J., & Roehrig, G. H. (2011). Impressions of a middle grades STEM integration program. *Middle School Journal*, *43*(1), 32–40.
13. Tran, N. A., & Nathan, M. J. (2010). An investigation of the relationship between pre-college engineering studies and student schievement in science and mathematics. *Journal of Engineering Education*, *99*(2), 143–157.
14. Moore, T. J., Stohlmann, M. S., Wang, H.-H., Tank, K. M., Glancy, A.W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In J. Strobel, S. Purzer, & M. Cardella (Eds.), *Engineering in precollege settings: Research into practice*. Rotterdam, the Netherlands: Sense Publishers.
15. Common Core State Standards Initiative. (2010). Common Core State Standards for Mathematics. Washington, DC: Council of Chief State School Officers and National Governors Association. Retrieved from http://www.corestandards.org/assets/CCSSI_Math Standards.pdf
16. Moore, T. J., Imbertson, P., Guzey, S. S., Roehrig, G. H., & Davis, M. (2013-2018). *EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Targeted Mathematics-Science Partnership* (DRL 1238140). University of Minnesota: National Science Foundation.
17. Clements, D. H. (2007). Curriculum research: Toward a framework for "research-based curricula." *Journal for Research in Mathematics Education*, *38*(1), 35–70.
18. Krippendorf, K. (2004). *Content analysis: An introduction to its methodology* (2nd ed.). Thousand Oaks, CA: Sage Publications.