

STEM Integration in the Middle Grades:

A Case Study of Teacher Implementation

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Abstract— Currently, there is a movement in precollege education to include engineering in the science curriculum. In the classroom, one manner of adding engineering to the precollege curricula is through STEM integration in science classrooms. This research project builds on the STEM integration research paradigm through a careful merging of the disciplines of STEM. There are two main types of STEM integration: content integration and context integration. This multiple-case study used content analysis to assess the type of integration used, if any, in the development of curricula for individual lessons and the unit as a whole. The findings demonstrated that, the overall STEM integrated curricula used content integration, but lessons within were either content integration, context integration, or single disciplined. Cases highlighted show these strategies, but cases that deviated significantly from this model are also highlighted. This research advances our understanding about how teachers develop STEM curricula in an interdisciplinary manner with the intent of implementing in precollege classrooms. It provides models of context and content integration across STEM and models of teachers' curriculum development in context-rich interdisciplinary problem spaces. By researching curriculum development, this project provides professional development designers models for quality programs that support interdisciplinary classroom environments.

Keywords—STEM integration; K-12 education; curricula

I. INTRODUCTION

Science, technology, engineering, and mathematics (STEM) subjects have been taught separately in K-12 schools for many years; however, new policy initiatives encourage the use of integrated approaches to teach STEM. Teaching STEM subjects in a more connected way using the context of real-world problems is the goal of integrated STEM education. This, in turn, makes learning of STEM more relevant to students' lives and helps them to see connections between and among STEM subjects, which can enhance motivation to learn STEM subjects and improve interest and persistence in pursuing STEM careers.

While there are different approaches to STEM integration, this paper presents two specific approaches: content integration and context integration. The goal is not to demonstrate which one is "the true" or better STEM integration approach. Instead,

the goal is to clarify these approaches and give insights to teachers and researchers who are interested in exploring these approaches. The paper investigates four STEM curricular units developed by teams of science teachers through a professional development program on STEM integration. All four units integrate science, mathematics, engineering, and technology with a particular focus on the life science topic of ecosystems.

The following research question guided the study:

- How are teachers implementing content integration and context integration of STEM disciplines to address engineering standards within life science curricular units?

II. BACKGROUND

A. Policy and Practical Significance

A number of groups and agencies are calling for improvements in STEM education [1]–[4]. The reports such as *Rising Above the Gathering Storm* [5] and *Prepare and Inspire: K-12 Education in Science Technology, Engineering, and Mathematics (STEM) for America's Future* [3] indicate that highly skilled individuals in STEM fields are needed to maintain global competitiveness. Improving STEM education in the U.S. has the potential of meeting demands by increasing the number of students pursuing STEM careers, providing a larger STEM workforce, and improving STEM literacy [2].

National policy documents are focusing their attention on STEM for primary and secondary education [6]–[9]. The Framework for K-12 Science Education describes the role engineering plays and how it can be used to help make science learning meaningful. Another national report supporting the integrations of engineering into STEM courses suggests that curriculum emphasize engineering design, integrate all disciplines of STEM, and encourage the development of engineering thinking [8].

In addition to these policy documents, states and national academic science standards have begun incorporating engineering. Many states have added engineering to their state standards [10] or are adopting *The Next Generation Science Standards* (NGSS) which includes engineering design [9],

increasing the need for integrating engineering into science curriculum. As a result, there is an increased demand to develop STEM integrated curriculum and professional development for teachers [11].

B. STEM Integration Framework

STEM integration is described as the blending of science, technology, engineering, and mathematics into one learning environment to (1) elevate students depth of understanding for each discipline by providing meaningful contexts for content learning, (2) increase student awareness through socially and culturally relevant situations, and (3) expand student interests in STEM fields [12].

There are six characteristics that have been identified for a quality STEM integration [13]. The first is providing a motivating and engaging context that will help student connect to the activities [14], [15]. Second, students engage in problem-solving, creativity, and critical thinking by participating in an engineering design challenge [16]. Third, student must learn from their failures through redesign [13]. Fourth, the lesson objectives must include mathematics, science, or both that enhance the engineering content [17]. Fifth, student-centered pedagogies should be used to foster learning [18], [19]. Finally, each lesson must include both teamwork [18], [20] and communications [8], [20], [21].

STEM integration may be accomplished in one of two ways: through content integration or context integration. Content integration merges two or more content areas together into one meaningful lesson or unit to allow student to understand “the big idea” and each discipline is essential to understanding that idea. For example, a unit on designing a method to clean up water in polluted ponds will incorporate meaningful engineering design as part of the design of the method, will introduce students to biological elements of clean water such as relationships within the ecosystem (i.e., interactions between biotic and abiotic factors, food webs, and human impact), and will have students doing meaningful data analysis such as analyzing pH, nitrogen, and phosphorous levels over time. Context integrations places the focus of one discipline above the others and uses the secondary disciplines to provide a setting or situation that creates meaning, relevance, and motivation for learning the primary content [12]. A good example of this would be a lesson where the context is designing a method to count pelican colonies from aerial photos in order to be able to save pelican nests from damage. The context is engineering design with an environmental impact, but the content is mathematics: unit area, perimeter, early ideas of density, and early ideas of ratio and proportional reasoning.

III. METHODS

To better understand how teachers thought about STEM integration in the design of their curricula, we used a multiple-case study design [21] that examined four STEM integration curricular units developed during a summer professional development institute. These units used engineering design as a means to teach ecosystems and environments, as well as data analysis and measurement. This research examined each unit

using content analysis [22] to identify how STEM was integrated into the curricular design. Individual lessons were identified as integrated if two or more disciplines were included. The lessons were then classified as using content integration if two or more subjects were described in the summary, identified specifically in the lesson objectives or the grade level standards, and were part of the lesson. Lessons classified as context integration used two or more subjects; however, there was primary content with the others supporting it but was not identified in other areas of the written curriculum.

A. Teacher Professional Development

The teacher fellows for this project participated in 3 weeks of professional development, coaching, and curriculum writing. The goal of these 3 weeks was to help teams of teachers to develop unit-length curricular modules to implement STEM integration through engineering design-based instruction that integrated meaningful science, data analysis, and measurement concepts. The first week was dedicated to engineering design understanding and pedagogies, as well as understanding data analysis and measurement pedagogies. The second week allowed teachers to dive deeply into the science content domains chosen (life science: ecosystems and environments, physical science: heat transfer and particle theory, and earth science: landforms and plate tectonics), focusing on how these content would fit into engineering design pedagogies and integrate data analysis and measurement. The curricula featured in this case study focus on ecosystems and environments. Week 3 had teams of teachers (2-4) along with project staff curriculum coaches working together to develop a first draft of their curricular unit.

The teacher fellows piloted portions of their draft curricular unit with students in a STEM summer camp setting with students ranging from grade 4-8. This pilot allowed the teacher fellows and coaches the opportunity to revise their curricula before implementing in their classrooms. The curricular units assessed in this research study are from this iteration of the curricular unit development.

B. Participants

The sample population for this study included ten participants who were all elementary or middle school teachers that developed four curriculum units for life science during the summer institute. The teachers are representatives of seven different schools within three districts (Urban/High Diversity District, Inner-ring Suburban/High Diversity District, and Suburban/Low Diversity District) in the Midwestern region of the United States. Tab I provides a detailed description of the participants demographic and affiliation detail. The modules selected for this study were limited to those developed for life science and had been implemented into the classroom before January, 2014. The framework of STEM content and context integration was used to assess how teachers implemented materials into their class lessons [12].

TABLE I. DEMOGRAPHIC OF PARTICIPANTS INCLUDING SCHOOL AND DISTRICT AFFILIATION.

Unit	Teacher & Grade	District
Space Plants	Brent (7)	School A: Suburban/Low Diversity
	Austin (8)	
Loon Nesting Platform	Kathy (6, 7)	School B: Inner-ring Suburban/High Diversity
	Krystal (6, 7)	School C: Inner-ring Suburban/High Diversity
	Megan (7)	
The Disappearing Moose	Nathan (7, 8)	School D: Urban/High Diversity
	Henry (7)	School E: Urban/High Diversity
Pollutants in the Pond/Lake Ecosystem	Tiffany (5)	School F: Suburban/Low Diversity
	Steven (5)	
	David (4)	School G: Suburban/Low Diversity

IV. CASES

The findings for this research for the four life science curricular unit or “cases” will be presented. Each case will include a brief description of the curricular unit followed by a description of how each case implemented content and/or context integrations. Finally, each case will be compared and discussed using a cross case analysis. For more information regarding the curricula or project, see <http://engteams.org>.

A. Space Plants

In this unit, students were asked to engineer a container that allows astronauts to transport and grow a plant from a seed while traveling from Earth to their destination (one month traveling time) so the plant will be partially developed upon arrival. Throughout the unit, students learned about the life cycle of a plant and the role that plants play within an ecosystem.

This unit was very strong on science content; however, the integration of mathematics was considerably better than the integration of engineering. Tab. II provides a description of each lesson and the type of integration used for each lesson. All the lessons that were classified as integrated were content integration. The first seven lessons focused on the life science content, which did include mathematics but made no mention of engineering. Three of the science lessons indirectly related to the final engineering project as the students took the science they had learned and created written proposals to NASA, their engineering client. For the first seven lessons, the curriculum could be modified slightly to begin integrating engineering deliberately into the science content. In addition, one lesson did also integrate technology.

TABLE II. SPACE PLANTS LESSON DESCRIPTIONS AND ANALYSIS OF CONTENT/CONTEXT INTEGRATION

Lesson: Description
<p>1. Controlled Experiment Soil & Water: Students worked in teams to investigate how the amount of water and the mass of soil affected plant growth over time. Students recorded water volumes, mass of soil, and plant growth for four weeks. They then analyzed collected data by calculating the mean, median, and mode to find patterns, made predictions, and drew conclusions.</p> <p>Type of Integration: Content; Science (introduction of abiotic factors that affect plant grow) & Mathematics (patterns in data); Engineering (none)</p>
<p>2. Energy, Producers, & Consumers: Students worked in teams to create a representation of a food web that described how energy flows through an ecosystem. Students then examined two different populations graphically to identify the producer/consumer relationship. The students were asked to predict proportions and types of organisms found at each level of an energy pyramid.</p> <p>Type of Integration: Content; Science (energy flow within food webs) & Mathematics (graphing multiple variable); Engineering - none</p>
<p>3. Photosynthesis Basics: In this lesson, students were introduced to photosynthesis first by differentiating products and reactants and then exploring an on-line simulation of photosynthesis. Students then created a visual representation of the products and reactants involved in photosynthesis. Finally, students examined plants and identified anatomical structures.</p> <p>Type of Integration: Context: Primary – Science (photosynthesis and plant anatomy); Supporting – Technology (prepare specimens and examine with microscope); No Mathematics or Engineering</p>
<p>4. Biotic & Abiotic Factors: The teacher introduced the concepts of abiotic and biotic factors by having students identify interactions within a familiar habitat. The teacher told students that abiotic factors are important for plant growth. Students then tested soil samples for specific abiotic factors (nitrogen, phosphorous, and pH) and predicted which soil composition should be used for germinating plants. Finally, students were asked to write a proposal to NASA describing the recommended soil composition needed to grow plant in space.</p> <p>Type of Integration: Content & Indirect Engineering Context; Primary - Science (soil composition) & Mathematics (data analysis techniques); Supporting - Engineering (proposed soil to client)</p>
<p>5. Light Intensity: In this lesson students determined how light intensity impacted photosynthesis through experimentation of Elodea (an aquatic plant). The students analyzed the results to determine the optimal distance and strength of light needed for seed germination. Next, students looked at whether data from four geographic locations where a specific plant grew to determine the conditions that encourage growth. Finally, the students wrote a letter to NASA offering two suggestions ideal for plant growth during space travel.</p> <p>Type of Integration: Content & Indirect Engineering Context; Primary – Science (light duration and intensity) & Mathematics (data analysis techniques); Supporting – Engineering (proposed light needed for plants during space travel to client)</p>
<p>6. Plant & Water Absorption: The teacher briefly discussed the location of water uptake and introduced the term osmosis. Students then examined the path water took through a plant by exposing a plant to dyed water. Based on the terms learned and preliminary observations, students predicted the movement of water over 24-hour period. The teacher then had students brainstorm how water leaves the cell. Finally, the teacher introduced the term transpiration.</p> <p>Type of Integration: No integration – Science only</p>
<p>7. Transpiration Rates: In this lesson students began by observing transpiration of plants by placing plastic bags over plants, which then collected condensed water within the bag. Next, students worked in teams to calculate the rate of transpiration using surface area measurements of a leaf to determine the amount of water a plant would lose over a 30-day period. Finally, students calculated the volume of water needed for 30 days and</p>

designed a container that will hold that amount of water for space travel.
Type of Integration: Content; Mathematics (calculating surface area), Science (determine rate of transpiration) & Engineering (design container for holding water)
8. Engineering Challenge: In the final lesson, students were introduced to the design challenge and asked to utilize what they had learned in previous lessons to engineer a container for growing and transporting a plant from a seed during its travel from Earth to Mars (about 30 days). In teams, students designed, constructed, and tested a prototype. They were then given additional constraints and asked to re-design their model. Finally, each team wrote a final proposal to NASA including all relevant specifications and recommendations and reflected on the process.
Type of Integration: Content; Engineering (design, construct, evaluate, re-design, test), Science (factors affecting plant growth) & Mathematics (surface areas, volumes and shapes for container)

B. Loon Nesting Platform

In this unit, students learned about ecology and ecosystems through the construction of loon nesting platforms. The loons are losing nesting sites due to human encroachment on their shoreline habitats. Students were to find a suitable 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 made an educated decision as to where to place their platform. Students then explored predator/prey relationships during the construction and redesign of their nesting platform.

This unit used both content and context integration in five of the lessons. Tab. III provides descriptions of the lessons and identifies the type of integration was implemented. These lessons primarily focused on vocabulary and relationships within an ecosystem. Lessons that did not include engineering could easily incorporate engineering by review or refocusing attention to the design process or the design challenge. The engineering design challenge integrated mathematics more strongly than science. However, the remaining two lessons were insufficiently described within the curriculum making it difficult to be sure if their lesson objectives aligned with what was written in the lesson plan.

TABLE III. LOON NESTING PLATFORM LESSON DESCRIPTIONS AND ANALYSIS OF CONTENT/CONTEXT INTEGRATION

Lesson: Description
1. Move It or Lose It: Human Impact of Nature: This lesson began by asking students to reflect on how humans impacted wildlife. They then modeled how humans have altered the locations available for the loon population to live in. Students made predictions about what would happen to the loon populations if similar conditions persisted. Next, the students compared and contrasted two different shorelines. Finally, the teacher introduced the engineering design challenge and the process of design.
Type of Integration: Content; Science (human impact on environment) & Engineering (introduction to process of design and the challenge); No Mathematics
2. Loon-ey Tunes: All About Loons: In this lesson, students found out information about loons. First, they listened and identified four different loon calls. Next, the students participated in a scavenger hunt to locate a variety of loon facts. The teacher explained the levels of organization: ecosystem, community, population, and organism. Finally, the students practiced identifying pictures that represented each of the vocabulary terms.

Type of Integration: No integration – Science only
3. Food Chains & Food Webs: Students investigated food chains and food webs using an internet search. The students identified relationships between producers, consumers, and decomposers as well as predatory/prey relationships.
Type of Integration: No integration – Science only
4. Loons Like Lakes: Choosing a Lake Platform: In this lesson, students were asked to compare living and non-living things and were introduced to the terms biotic and abiotic. Students were then asked to investigate local lakes to determine which ones were suitable for placing a nesting loon platform.
Type of Integration: Content & Context; Primary – Science (abiotic/biotic factors, examination of local area maps) & Engineering (identify a location for loon platforms); Supporting – Mathematics (use qualitative and quantitative data)
5. Nest Sweet Nest: Nest Survey: Students began the lesson by reviewing the stages of the design cycle to identify where the stage they were in. Next, students were asked to identify which type of bird lived in what type of nest by measuring the size of the nests and the mass of the birds. Students analyzed the characteristics of each nest to determine the advantages and disadvantages of each design.
Type of Integration: Content & Context (Engineering); Primary – Mathematics (calculate mass and nest sizes) & Science (qualitative analysis of nests); Supporting – Engineering (reviewing stage of design cycle)
6. If You Build It, They Will Come: In this lesson, students reflected on what they have learned. In teams, students designed, built, and tested their nest prototype. They scored their nest against a scoring rubric to evaluate the success of their design. Finally, one member of each team explained what worked well for their team's nest design.
Type of Integration: Content; Engineering (plan, build and test within constraints), Mathematics (calculate areas of different shapes, scaling models) & Science (buoyancy)
7. Predatory/Prey Relationship: Students investigated the predator/prey relationship between loons and fish.
Type of Integration: No integration – Science only
8. Re-design Nesting Platform: In the final lesson, students re-designed to improve their initial nesting platform design.
Type of Integration: Content; Engineering (plan, build, and test within constraints), Mathematics (areas of different shapes, scaling models) & Science (buoyancy)

C. The Disappearing Moose

This unit was contextualized around the declining moose population. The moose is one of the largest land mammals on Earth; however, in the upper Midwest'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 learned that bioengineers have developed 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 the upper Midwest.

This unit used a variety of different implementation strategies including content integration, context integration, and no integration. A more detailed description of each lesson may be found in Tab. IV. Simple modifications, such as introducing the design challenge during lesson one, could be

used to improve the integration of engineering into the unit. The following lessons could then reinforce the purpose of the lessons by reminding students of the challenge that waits. The engineering design challenge lessons were the only lessons that integrated mathematics, science, and engineering. In addition, the life science learned was used to provide a context for the engineering lesson but relied more on physical science to build the dispersal tool.

TABLE IV. THE DISAPPEARING MOOSE LESSON DESCRIPTIONS AND ANALYSIS OF CONTENT/CONTEXT INTEGRATION.

Lesson: Description
1. This is a Moose: This lesson introduced students to the moose through video and discussion. Students were then asked to examine moose populations and identify trends within those populations. Students investigated the moose and its habitat. Finally, students made predictions about what was causing the decline in the moose population.
Type of Integration: Context: Primary – Science (habitats and animal characteristics); Supporting – Mathematics (graphing, identify patterns); No Engineering
2. So You Say, It's Predator/Prey: Students proposed possible causes for the decreased moose populations and investigated how the wolves might be a factor. By graphing both animals populations and identifying trends between the two, students identified a predator/prey relationship.
Type of Integration: Context: Primary – Science (predator/prey relationships); Supporting – Mathematics (graphing, finding patterns, and analyzing data); No Engineering
3. Other Factors: Students investigated moose mortality using a variety of articles supplied by the teacher. Students then generated a list of factors contributing to the decreasing population of moose including biotic and abiotic relationships.
Type of Integration: No integration; Science only
4. What Can We Do?: In this lesson students were introduced to the engineering design challenge and asked to sketch two solutions for reducing the tick populations that effect moose in the local area.
Type of Integration: Content: Science (articulate the effect of the moose tick on moose populations) & Engineering (identify and sketch solutions); No Mathematics
5 How Do Scientists Estimate Populations?: This lesson began with students generating ideas about how scientists estimated population size. Students then modeled the phase of populations using random sampling. Students compared the mean, median, and mode of each sample populations.
Type of Integration: Content: Science (population dynamics) & Mathematics (statistical comparisons of samples to estimate population); No Engineering
6. How Does Nature Disperse Things or Get Rid of Parasites?: In this lesson, students researched how organisms have adapted to disperse seeds, eggs, and defense chemicals. Students were then encouraged to incorporate these ideas into their “tick-ta-cide spreader”.
Type of Integration: Content: Science (adaptations of dispersal mechanisms) & Engineering (improving design of dispersal unit); No Mathematics
7. Coniferous Forest: Why Do All These Organisms Live Here?: Students identified factors that made one location a suitable habitat for moose as compared to others. They considered food webs, abiotic and biotic factors, and the relationship each has to the moose.
Type of Integration: No integration; Science only
8. Engineering Design Challenge: Plan, Implement, Test: In this lesson, students worked in teams to plan and build a “tick-ta-cide spreader”. Students then tested their model and scored it against constraint criteria.
Type of Integration: Context: Primary – Engineering (designing dispersal

mechanisms for spreading poison); Supporting – Mathematics (surface area and volume) & Science (nature inspired design)

9. Engineering Design Challenge: Implement, Test & Redesign: Students tested their dispersal apparatus and identified ways to improve on the design.

Type of Integration: Context: Primary – Engineering (testing and redesign); Supporting – Mathematics & Science

10. Engineering Design Challenge: Test, Redesign, Share: Students tested their dispersal apparatus and identified ways to improve on the design.

Type of Integration: Context: Primary – Engineering (build modified prototype, test and evaluate); Supporting – Mathematics and Science

D. Pollutants in the Pond/Lake Ecosystem

This unit focused 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 in an aquatic ecosystem, and the history of a local body of water. Students observed a nearby pond/lake, collected and examined water samples and identified organisms found in the area. Students ultimately designed a barrier or other means of stopping or slowing fertilizer from running off into a model pond/lake.

This ten-lesson unit used a combination of lessons, some which integrated STEM and others that did not. Tab. V provides a detailed description of the type of integration or lack thereof, for each lesson. The first six lessons were science lesson where half did not integrate STEM, two used content integration and one used context integration. Of these first six lessons, engineering was not included. However, engineering lessons did use context integration but the mathematics and science were somewhat weak.

TABLE V. POLLUTANTS IN THE POND/LAKE ECOSYSTEM LESSON DESCRIPTIONS AND ANALYSIS OF CONTENT/CONTEXT INTEGRATION.

Lesson: Description
1. Lake/Pond Food Web: Students began the lesson by working in partners to create a food web. They examined each food web looking for patterns. Students learned science vocabulary that described the participant in the food web such as consumer or producer. Finally, students predicted what would happen to the food web if one or more parts were altered.
Type of Integration: No integration; Science only
2. Owl Pellet Dissection: Students investigated the feeding habits of owls, which is an organism found in a lake/pond ecosystem. Students dissected the owl pellets, reconstructed the skeletal remains, and calculated the energy provided by each consumed organism.
Type of Integration: Content: Science (food webs and energy flow) & Mathematics (calculating energy); No Engineering
3. Mississippi River Organism Identification: In this lesson, students used a dichotomous key to investigate invertebrate organisms.
Type of Integration: No integration; Science only
4. Field Trip to Pond/Lake: Students visited a pond/lake to collect water samples and observed the ecosystem. Students then identified relationships within the pond/lake ecosystem.
Type of Integration: No integration; Science only

<p>5. Pond/Lake Data: Using pond/lake water samples, students observed and recorded the number of organisms living in the sample then created a food web. Students also tested the amount of phosphorus in the sample. All data were compiled into charts and graphs and analyzed.</p> <p>Type of Integration: Content; Science (food webs, relationships in an ecosystem) & Mathematics (create and analyze graphs); No Engineering</p>
<p>6. Fertilizer and Pond/Lake Life: Students designed and conducted an experiment to observe the effects of fertilizers have on aquatic plants. Students collected and analyzed qualitative and quantitative data.</p> <p>Type of Integration: Context; Primary – Science (experimentation, factors effecting ecosystems); Supporting – Mathematics (measuring, recording, graphing); No Engineering</p>
<p>7. Engineering Design (Introduction): Students began this lesson by re-examining how fertilizers affect aquatic plants. Students analyzed how fertilizers have contaminated and affected Horseshoe Lake. Students were then introduced to the engineering design challenge and asked to design barrier that keeps fertilizers from entering the lake. They completed a cost analysis of their sketched design.</p> <p>Type of Integration: Content; Engineering (identify problem and plan solution), Science (impact of fertilizer usage) & Mathematics (interpreting graphs)</p>
<p>8. Engineering Design: After reviewing the design challenge, students built, tested, and evaluated their prototype. Students then reflected on possible ways they might improve their design.</p> <p>Type of Integration: Context; Primary – Engineering (build, test, and evaluate); Supporting – Science (water clarity) & Mathematics (volume)</p>
<p>9. Redesign Barrier: The teacher began this lesson by showing students solutions that engineers had already used to prevent fertilizer runoff. Students were then asked to improve their design and test it. Finally, they created a short presentation to communicate their results.</p> <p>Type of Integration: Context; Primary – Engineering (re-design, build, test, and evaluate); Supporting – Science (water clarity) & Mathematics (volume)</p>
<p>10. Guest Speaker: A guest speaker came to speak with the students about the development of natural and manmade ponds, and the challenges they face with runoff and other pollution. Students shared their designs with the guest speaker.</p> <p>Type of Integration: Content; Engineering (What do real engineers do?) & Science (human impact); No Mathematics</p>

V. CROSS CASE ANALYSIS

Although the type of integration varied from lesson to lesson, the units as a whole used content integration with mathematics, science, and engineering. The four curricular units were generally organized in a similar fashion. The first set of lessons in the units served as science lessons that provided background needed for the engineering challenge, then ended with the engineering project. One main difference between these was whether or not the teacher used the science lesson as a part of the design cycle (problem/background) or just as prerequisites for engineering.

A. Life Science Lessons

For the science specific lessons, the curricula used three different approaches to begin each unit. All of the units began with a science lesson; however, only one of the four units, *Loon Nesting Platform*, began by introducing the engineering challenge up front. *The Disappearing Moose* engineering introduction occurred in lesson four. The remaining two units

waited to introduce engineering until the design challenge. These three units could have easily integrated some level of engineering by introducing the engineering design process during this introductory lesson. In addition, these introductory lessons varied in the types of integration used, one beginning with context integration, two with content integration, and one with no integration.

As with the first lesson of each unit, the following science lessons included a wide variety of integration. Each unit included two to four integrated lessons and two or more where no integration occurred, not including the initial lesson. Those lessons that did use integration primarily integrated science and mathematics with a few exceptions. For example, *Space Plants* used content integration of science and mathematics for the majority of lessons, yet engineering was never directly addressed within the lessons until the design challenge. The *Loon Nesting Platform* and *The Disappearing Moose*, on the other hand, did directly include engineering in two lessons preceding the engineering design challenge and both used a combination of content integration and context integration. The other unit, *Pollutants in the Pond/Lake Ecosystem*, used a combination of context and content integration for science and mathematics but did not include engineering in these science lessons.

B. Engineering Design Challenge

The lessons specific to the engineering design challenge appeared at the end of the unit lessons. When combining all the engineering design specific lessons, overall integration used was content integration. Additionally, the lessons that are specific to the engineering design challenge also implemented integration of engineering, mathematics, and science for the purpose of creating solutions for a life science problem, however, the approach differed. For the four curricular units analyzed, *Pollutants in the Pond/Lake Ecosystem* implemented content integration for the first of three engineering lessons and context integration for the other two, while *The Disappearing Moose* used context integration, and *Space Plants* and *Loon Nesting Platform* units used content integration. Most of the curriculum units divided engineering into multiple lessons with the exception of *Space Plants*, which included only one lesson that spanned over several days. As a result, the lesson was taken as a whole and found to employ content integration. The *Loon Nesting Platform* was unique in the implementation of content integration as it did focus some of the attention on scaling models, while the other units reinforced the prior lessons to varying degrees.

VI. DISCUSSION

The *Next Generation Science Standards* (NGSS) [9] clearly outline what students should learn and be able to do in science classes. There is a growing need to teach science through integrated approaches so that students learn concepts from STEM disciplines and make coherent connections between them. Integrated STEM education may better prepare students for an increasingly complex world.

As we began helping science teachers learn and then teach science through STEM integration approaches, we found two

different types of STEM integration strategies teachers used: content integration and context integration. Our analysis suggests that, although teachers use context integration for many of the lessons in their unit, the units as a whole used content integrations of mathematics, science, and engineering. Content integration is a great opportunity for depth coverage of in each STEM discipline. Teachers, in this study, were very good at incorporating science into the life science units as expected. Furthermore, teachers seemed better equipped to integrate mathematics into their lessons than engineering. It also appeared that teachers were generally able to integrate two disciplines but rarely was a third discipline integrated within the science lessons. Finally, making the conceptual connections between the STEM disciplines was challenging for science teachers. Given that STEM integration is new for many teachers, they may need more guidance in integrating three or four STEM disciplines.

VII. CONCLUSION AND IMPLICATIONS

This research advances pedagogical understanding about how to teach STEM content in an interdisciplinary manner in precollege classrooms. It posits the theoretical models of context and content integration across STEM and models of student learning in these context-rich interdisciplinary problem spaces. By researching the implementation of K-12 engineering standards through STEM integration, this paper adds to the theoretical basis for curriculum development in STEM integration environments where engineering is the key to the integration.

As mentioned earlier, the current science and engineering education reforms [8], [9] ask science teachers to present science using integrated STEM approaches. In order to adopt such an approach, the teachers need to engage in quality professional development programs such as the one presented in this paper. In addition to strengthening teachers' science content knowledge in engineering and mathematics, professional development in the development and implementation of innovative STEM curriculum materials is critical.

We have found that teachers in our study are interested in teaching science using integrated approaches since their schools are also planning for that change. If teachers and administrators think that integrated STEM is an effective way to engage more students in STEM disciplines, teachers seek out opportunities to adopt STEM integration approaches. Quality STEM integration requires collaboration between teachers, administrators, and district coordinators.

ACKNOWLEDGMENT

The work described in this paper was supported by the National Science Foundation under grant numbers NSF EEC/CAREER-1055382 and DUE-1238140. The opinions, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the view of the National Science Foundation.

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