Assessment of Curricular Materials for Integrated STEM Education (RTP, Strand 4)

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Assessment of Curricular Materials for Integrated STEM Education

Improving K-12 STEM education has a priority on numerous education reforms in the U.S.[1-7] To that end, developing and sustaining quality programs that focus on integrated STEM education is critical for educators. Integrated STEM education provides authentic contexts for learning and enables students to make connections among the STEM disciplines, as well as supports developing knowledge and skills within and across the STEM disciplines[8]. Engineering is a critical element of integrated STEM education as it can be seen as a vehicle to teach and learn science and mathematics[1]. At the K-12 level, engineering education should (1) include and emphasize engineering design, (2) incorporate important and developmentally appropriate science, mathematics, and technology knowledge and skills, or (3) promote engineering habits of mind which are the general principles of K-12 engineering education[1].

Successful implementation of any integrated STEM program is related to the curriculum materials used[9]. Educators increasingly recognize the challenge of finding quality curricular materials for integrated STEM education. In this study, forty-eight teachers participated in a year-long professional development program on STEM integration funded by National Science Foundation (NSF). Teachers designed twenty STEM curriculum units as a part of the project. Each STEM curriculum unit includes an engineering challenge in which students use or develop technologies to solve the challenge and integrates grade level appropriate mathematics (data analysis and measurement) and one of the three science content areas: life science, physical science, or earth science. The study aims to evaluate the STEM curriculum units developed by the project teachers. We also investigated whether there was any difference in the level of quality of these STEM curriculum units between different science content areas (life science, earth science, and physical science).

Integrated STEM Education

In 2011, the President's Council of Advisors on Science and Technology (PCAST) recommended that 100,000 new STEM teachers be prepared with strong teaching skills and content knowledge by 2020 to advance STEM instruction in the U.S. Moreover, recent reports by the National Research Council and National Academies of Engineering have called for shifts in approaches to STEM instruction[1-5]. The new efforts with STEM reform share a focus on integrated approaches to teaching STEM[8]. The new integrated approaches to STEM instruction address the need for explicit and intentional integration of STEM subjects. Science teachers, for example, are expected to teach intersecting concepts and core disciplinary science using scientific and engineering practices as identified in Next Generation Science Standards (NGSS)[10]. The integration of mathematical reasoning, problem solving and technological literacies to scientific and engineering practices are grounded in NGSS as well.

There is not a single right approach for STEM integration, STEM integration can take many forms[9]. For instance, in K-12 science classes, engineering can be used a context to teach core science concepts and process skills. Learning science through completing engineering design challenges helps students to learn science concepts [11-14] and increase their interest in learning science and engineering[11].

While integrated STEM education is critical to improve STEM education, it presents some challenges. One of the most significant challenges centers on finding quality curriculum materials. Since integrated STEM education is relatively new, few resources are now available for the teachers[15]. This would require teachers to develop their own curricular materials. However, curriculum development is a complex process for most teachers.

There are several fundamental considerations when developing an integrated STEM curriculum unit[8]: addressing rigorous science and mathematics standards, having students participate in an engineering design challenge that has a motivating and engaging context, allowing students to learn from failure while providing opportunities for re-design, using student-centered pedagogies, and promoting communication skills and teamwork. It is important to make sure that every single learning activity is coherent and tied to the engineering challenge in a STEM curriculum unit.

The Study

Context

To address the need to help teachers to develop their own curriculum units for integrated STEM education, we have developed a professional development program for 200 science teachers (grades 4-8). The program has two components: professional development and curriculum development. In this program, teachers participate in a 3-week summer institute and then receive support through coaching and mentoring during the subsequent academic school year. In the summer institute, teachers learn engineering design and practices and explore targeted science concepts through completing design activities. Teachers also work in small groups to design STEM curriculum units. Following the summer institute, teachers pilot their unit with a small group of summer camp students. Afterward, teachers revise their unit based on what they have learned and experienced in the summer pilot. Finally, teachers implement their revised unit in their own classrooms during the academic school year.

The project is currently in its second year. In the first year of the project, twenty STEM integration units were developed and implemented by the project teachers. Each unit focused on one of the three science concepts (i.e. ecosystems, plate tectonics and erosion, and heat transfer and particle theory), integrated data analysis and measurement for mathematics, included an engineering design challenge, and allowed students to develop technologies through completing the engineering challenge or use technologies to solve the engineering challenge. Among those 20 units, seven focused on life science (ecosystems), seven addressed earth science topics (plate tectonics or erosion), and six focused on physical science (heat transfer or particle theory). Each unit included 5-10 lesson plans. Table 1 shows an overview of a STEM unit developed by three middle school life science teachers. In this unit, loon nesting platform design was chosen as a context to make learning more relevant to student lives (Loons are the official state bird where the curriculum was implemented). The unit addressed the following NGSS: MS-ETS 1 Engineering design, LS2C: Ecosystems dynamics, functioning, and resilience, and the crosscutting concepts: stability and change.

Table 1: Overview of the loon nesting platform unit

Title	Description
Lesson 1: Move It or Lose It	This lesson begins by asking students to reflect on how humans impact wildlife. Students then model how urban development has impacted the locations available for the Common Loon to nest. Students then make predictions about what would happen to the loon populations if similar conditions persist. Finally, the teacher introduces the engineering design challenge and the process of design. The challenge charges students to design nesting platforms for loons in lakes where shoreline habitat has been lost.
Lesson 2: Loon-ey Tunes	In this lesson students learn about loon behaviors and adaptations. Students are asked to make predictions about loon facts, then through a scavenger hunt, learn about the natural history of loons. The teacher then explains the levels of biological organization: ecosystem, community, population, and organism. Students create a foldable to illustrate the relationship between the four levels. Finally, students practice identifying pictures that represent each of the levels.
Lesson 3: What's for Dinner?	Students investigate food chains and food webs using a web based animated food chain game. They then create their own food web that includes the Common Loon. On this web activity, students identify the roles and relationships of the organisms (producers, consumers, and decomposers as well as predatory/prey relationships).
Lesson 4: Loons Like Lakes	In this lesson student are asked to compare living and nonliving components of an ecosystem and are introduced to the terms biotic and abiotic. Students are then asked to analyze data about several local lakes to determine which is best suited for placement of a loon nesting platform. Students are able to choose any lake as long as their decision is supported by the data they present.
Lesson 5: Nest Sweet Nest: Nest Survey and Design	Students begin the lesson by reviewing the stages of the engineering design cycle to identify where they are. Students make observations of various bird species and their nests, then analyze the characteristics of each nest to determine the advantages and disadvantages. Students then decide on the dimensions and shape of a next appropriate for looks. Since loon nests are large, their prototypes will be scaled to 25% of the actual nest dimensions. Finally, students create a nest template that is used as pattern in building their nest prototypes.
Lesson 6: If You Build It, They Will Come	In this lesson, students are presented with the criteria and constraints of their prototype. Individually, then in teams, students decide on a design, then build and test their prototype. Prototype nests are scored according to a scoring rubric to evaluate the success of their design.
Lesson 7: Your Best Nest	In the final lesson, students redesign their prototype to make improvements to their original design. Students summarize their learning from the unit in a small poster project, which is presented to the class.

The units were assessed using STEM Integration Curriculum Assessment (STEM-ICA) tool. STEM-ICA was developed by the authors and is composed of nine specific ratings/items and an overall rating. The nine items are: motivating and engaging context, engineering design, integration of science content, integration of mathematics content, instructional strategies, teamwork, communication, assessment, and organization. STEM-ICA closely aligns with the framework for quality STEM integration[8]. Each of these nine constructs was operationally defined to pull out components of student learning. Here we present two of the constructs in detail: motivating and engaging contexts and engineering design. Motivating and engaging contexts were defined to include realistic situations, address issues of personal meaningfulness to students, incorporate issues that are relevant to students with a variety of backgrounds, and provide a compelling purpose for doing the STEM integration activity (including global, environmental, social contexts and/or current events or issues). Engineering design was operationalized by addressing a complete engineering design cycle to develop a relevant technology while working for a client, allowing students to learn from failure and redesign, providing the students with opportunities to think like engineers (e.g., use engineering habits-of-mind and engineering tools and processes), and exposing students what engineering is and what engineers do at work. Figure 1 shows item II, engineering design.

Each item in the STEM-ICA is rated on a 5-point scale from 0 to 4 (0: not present, 1: weak, 2: adequate, 3: good, 4: excellent). Yes/No questions help the reviewers to respond to the item. Yes/No questions were included since the items included several indicators. For example, as shown in table two engineering design includes several indicators (e.g., re-design, habits of mind). Yes/No questions help the reviewers better understand the items and their indicators.

Figure 1: Item II, Engineering design

Does the curriculum unit…

Contain activities that require students to use engineering design processes?
Allow students opportunities to learn from failure/past experiences?
Allow students to redesign?
Contain an engineering challenge that includes a client?
Allow students to participate in an open-ended engineering design challenge in which they design and assess processes or build and evaluate prototypes/models/solutions?
Contain an engineering challenge that requires students to consider constraints, safety, reliability, risks, alternatives, trade-offs, and/or ethical considerations?
Promote engineering habits of min?
Requires students to explore and develop technologies from the field of engineering discussed in the engineering challenge?
Promote understanding about what engineering is and what engineers do at work?

3. To what extent does the curriculum unit allow students to learn engineering design by integrating an engineering design challenge?

NA/DK	0	1	2	3	4

Describe the evidence that supports your ratings:

Eight reviewers assessed the quality of the curriculum units. Reviewers, PhD students in STEM Education in a Midwest university, attended a two-hour workshop to learn about the assessment tool and individually rated three STEM units that were developed by professional curriculum designers. 91% of the ratings provided by reviewers were in perfect agreement. All the reviewers discussed their scores in a second meeting and came to a consensus in all scores. Reviewers then started to assess the 20 curriculum units developed by the project teachers. As noted earlier, project teachers developed their units and piloted them in a small summer camp. They revised their units after the summer pilot. The first draft and revised version of the units were submitted to the project team. For the purposes of this paper, we focused on assessment of the revised curriculum units.

Results

The descriptive statistics and Kruskal-Wallis test[16] were used to analyze the data. Table 2 shows the scores of the units. From 20 STEM curriculum units, five of the units (one life science unit, two physical science units, and two earth science units) were scored a three (good) for the overall quality. The majority of the units (15 units) received a score of two (adequate) or one (weak) for the overall quality. No single curriculum unit was scored a four (excellent) for the overall quality. For item 1, engaging and motivation context, only two physical science units were received a four. The remaining four physical science units were scored a three. From seven earth science focused STEM curriculum units, two of them were scored a three and five of them scored a two for the context that they used. For the life science units finding an engaging context seemed more challenging. One unit was scored a three, three units were scored a two, and three units were scored a one for the context. Only one unit was scored a four for the engineering design challenge (Item 2). This unit was a physical science unit and addressed all the elements for a quality engineering design challenge identified in the STEM-ICA. All the other STEM units included an engineering design challenge; however, they did not include one or more of the critical elements of an effective engineering design. From 20 STEM curriculum units none of them were scored higher than a three in the categories of science integration (Item 3) or mathematics integration (Item 4). Eight units (four physical science, two earth science, and two life science) were scored a three for science integration. Six units (four physical science and two earth science) were scored a three for mathematics integration. From those units, five of them were scored a three for both science and mathematics integration. For item 5, instructional strategies, the lessons in each unit were analyzed to find out if they were student-centered. A student-centered lesson requires students to complete and analyze information and data before arriving at a solution and embeds STEM ideas to be learned in multiple modes of representations (e.g., manipulative, pictures, symbols) with an emphasis on transitions within and between modes. Two physical science units and one earth science unit were scored a four for instructional strategies. Teamwork (item 6) was evident in all the 20 STEM curriculum units. All the curriculum units require students to collaborate with other students to complete the activities or to solve the engineering challenge. No single STEM curriculum unit was scored a four for communication (item 7). None of the STEM curriculum units was scored a four for assessment (item 8). To receive a four, a curriculum unit should include formative and summative assessments and these assessments should be closely aligned to the goals and objectives of the unit and state standards. Moreover, assessments should provide guidance to the teacher to improve the implementation of the unit. Only four units received a score of three. The organization of a STEM unit is critical. Only one physical science unit was scored a four for the organization.

Figure 2 shows the Kruskal-Wallis test results. The Kruskal-Wallis test results showed that (H (2) = 5.88 p=.74), meaning no statistically significant difference in the level of the quality of STEM units was found between different science content areas (life science, earth science, and physical science). However, there was statistically significant difference between groups on item 1, motivational context. Physical science curriculum units had higher rankings for the motivational context.

Table 2: Raw scores

	Item #1 Context					*Item #2 Engineering*					*Item #3 Science*				
	0	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
LS		* *	* * *	* *			* * *	* * *	*		*	* * *	*	* *	
ES			* * * * *	* *				* * * *	* * *			*	* * * *	* *	
PS				* * * *	* *		*	* * * *		*		*	*	* * * *	

	Item #4 Mathematics					*Item #5 Pedagogies*					*Item #6 Teamwork*				
	0	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
LS	*	* * *	*	* *			* *	* * *	* *		*	* *	*	* * *	
ES		* * * *	* * * * *				*	* * *	* *	*			* * * * *	* *	
PS		* *		* * * *				* *	* *	* *	*		* *	* *	*

	Item #7 Communication					*Item #8 Assessment*					*Item #9 Organization*					*Overall*				
	0	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
LS	*	*	* *	* * *			* * *	* * * *				* * *	* *	* *			*	* * * * *	*	
ES		*	* * *	* * *			* * *	* *	* *			* * *	* * *	*			* * *	* *	* *	
PS			*	* * * * *			*	* * *	* *			* *	*	* *	*		*	* * *	* *	

NOTES: LS: Life science, ES: Earth science, PS: Physical science. * represents a curriculum unit. For example, 2 Life science units were scored a one for item #1

Figure 2. Results of the Kruskal-Wallis test for STEM curriculum units

	Item#1 Context	Item #2 Engineering	Item #3 Science	Item#4 Math	Item #5 Pedagogies	Item #6 Teamwork	Item #7 Communication	Item #8 Assessment	Item #9 Organization	Overall
H	9.25	3.50	2.93	2.46	3.36	0.63	2.96	1.95	1.07	5.88
df	2	2	2	2	2	2	2	2	2	2
p	.01*	.17	.23	.29	.18	.72	.22	.37	.58	.74

*$p<.05$, N = 20

Discussion and Conclusions

There have been many calls for advancing STEM education in the U.S.[1-7] While most of these reforms, in general, address one of the STEM subjects, recent reforms emphasize the connections among the STEM subjects. Advocates of integrated STEM education argue that teaching STEM subjects in a more integrated manner can help students to better understand the STEM subjects and enhance their motivation to pursue a STEM career[2]. One approach for integrated STEM education is to apply engineering as a context to teach science and mathematics[1]. In our professional development program teachers learned and designed engineering design based curriculum materials in order to teach STEM subjects in an integrated manner. Findings of the study showed that the project teachers were able to develop STEM units, which included an engineering challenge that required students apply science and mathematics. While all the units had a similar level of quality, physical science focused units were found to have a more engaging and motivating context. The topic addressed in physical science units was heat transfer so the teachers designed units that asked students to design and built containers to protect food from heat or cold depending of the context chosen. Earth science (plate tectonics and erosion) focused units included engineering challenges such as selecting sites to safely build and anchor buildings in an earthquake prone area. Life science focused STEM units' engineering challenges were related to ecosystems (e.g., designing a barrier to cut of fertilizer run off or designing animal nests).

No statistically significant differences were found between the life science, physical science, and earth science STEM curricular units when three groups were compared (overall rating). However, group comparisons for each item on STEM-ICA showed the difference among groups for item 1, engaging and motivating context. The results showed that the context of the engineering activities developed by the physical science teachers were more engaging and motivating comparing to the authentic contexts used by life science and earth science teachers. Using a motivating and engaging context is critical in integrated STEM education[8]. Realistic contexts motivate students and help them engage in their learning. Additional support to life science and earth science teachers during the curriculum design process may assist them in creating more engaging contexts for their STEM curricular units.

The results of the study illustrated that teachers also needed more support in integrating science and mathematics, providing opportunities for students to communicate science concepts, mathematical thinking, and engineering thinking, and embedding well-developed formative and summative assessments to the STEM units. Mathematics integration is difficult for most science teachers. A reason might be that science teachers do not have enough subject-matter knowledge to teach mathematics effectively. Developing science lessons that are well connected to the engineering challenge also seems challenging for the teachers[15]. One common concern associated with student communication is that presenting science, mathematical, and engineering thinking and design solutions requires time, thus it became a missing element in several curriculum units. However, it has been shown that communicating science, mathematical, and engineering thinking foster STEM learning[14]. Assessment design for integrated STEM teaching is challenging since it requires assessing student learning of multiple disciplines of STEM. Commonly used assessments such as quizzes and exams may not provide enough information about student learning of STEM[10]. Providing teachers more support or just-in-time support in these three areas in a professional development program may contribute to improving STEM curriculum design.

Despite the rise in interest in integrated STEM education, there is little research on the quality of STEM curricular materials and professional development opportunities for teachers to successfully integrate STEM. This study provides evidence for the impact of a professional development program that aims to provide opportunities for teachers to explore STEM integration and develop their own STEM units. Thus, the study findings have implications for the design of new STEM education professional development programs for teachers. First, teachers need opportunities to learn new knowledge and skills to implement integrated approaches and new curricular materials for implementing an integrated program. Using integrated approaches may be particularly difficult for teachers as it deals with teaching not only science content but also mathematics and engineering. Most science teachers are not confident in teaching mathematics and engineering. Providing teachers opportunities to practice STEM curriculum units in professional development programs might help teachers to increase their understanding of engineering, to improve their practices, and to gain confidence in using integrated STEM approaches. Second, providing teachers more support in the areas of science integration, mathematics integration, communication, and assessments in a professional development program may contribute to improving STEM curriculum design and teaching.

In this study, we explored the STEM curriculum units that a group of science teachers developed as they participated in a professional development program that focused on integrated STEM education. Our future research focuses on reporting teachers' stories of the implementation of the STEM units in their own classrooms. As we investigate their stories of development and implementation of integrated STEM units, we will be able to see and examine their experiences closely. Stories of science teachers as STEM curriculum makers can help us, as researchers and educators finding strategies for teachers to counter barriers to integration.

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