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Linking the E and M in STEM

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Linking the "E" and "M" in STEM (Research to Practice)

Strand: Engineering across the K-12 curriculum: Integration with the Arts, Social Studies, Science, and the Common Core

Defining the Need

Understanding engineering, science, and mathematics are critical skills for our modern world. In order to understand this world, it is vital to foster engineering and technological literacy among all people, starting with young children. Technology and engineering are new fields at the elementary school level; however, this is where such education needs to start. Just as it is important to begin science instruction in the primary grades by building on children's curiosity about the natural world, it is crucial to begin technology and engineering instruction in elementary school by fostering children's natural inclination to design and build things, and to take things apart to see how they work.[1] It is during primary school that students establish first impressions of possible career options.[2] This is a critical time to introduce the fields of technology and engineering as exciting choices before students develop many of the stereotypes that often discourage girls and minorities from pursuing courses and careers in technical fields.[3] Finally, at all educational levels, hands-on technology lessons can help make mathematics and science content relevant to students by illustrating these subjects' application in real-world projects.[4]

Although technology and engineering are new fields at the elementary school level, elementary teachers are under pressure to meet nationally determined learning goals around math, science, engineering, and technology. This has been particularly emphasized in the emergence of the Common Core State Standards (CCSS) in Mathematics and English Language Arts[5] and the publication of the Next Generation Science Standards (NGSS).[6] Many areas of these new standards, such as the Standards for Mathematical Practice in the CCSS and the Science and Engineering Practices in the NGSS, focus on the "real world" application of content and skills. Elementary teachers are working to meet these national standards by integrating content areas, most often math and science, in order to emphasize the real world application of learning goals for students. According to Davison, Miller, and Metheny, "The key thought behind this process [of integration] is to develop relevancy and applicability of the disciplines to the existing student experiences. The 'doing' of mathematics and the 'doing' of science creates a new way for students to look at the world".[7] The National Council for Teachers of Mathematics highlights the importance of integrating math topics into other subjects in the "Connections" strand of their standards: "School mathematics experiences at all levels should include opportunities to learn about mathematics by working on problems arising in contexts outside of mathematics. These connections can be to other subject areas and disciplines as well as to students' daily lives."[8]

Engineering is one such subject rich with possibilities to connect with math. Teachers must be prepared to help students make the connection between math and engineering and could benefit from high- quality professional development to guide them in the process. Thus, through the design and implementation of a professional development workshop, we sought to explore: What should be the key components of a learning opportunity designed to help teachers meaningfully integrate math and engineering topics in their elementary classrooms?

Teachers want to learn about integration

We initially designed the professional development experience based on results from a survey of 62 K-5 teachers who attended a workshop on the Engineering is Elementary (EiE) curriculum. The survey asked teachers about their most pressing professional development needs. Of the 62 respondents, 74% indicated they were interested in professional development to integrate their current engineering curriculum with mathematics. Seventy one percent of respondents said they would find an organizational tool helpful for planning integrated lessons for their students.

A second survey was e-mailed to 1262 teachers who had participated in previous EiE workshops. Of those e-mailed, only 97 participants responded. The results for this survey are depicted in Figure 1.

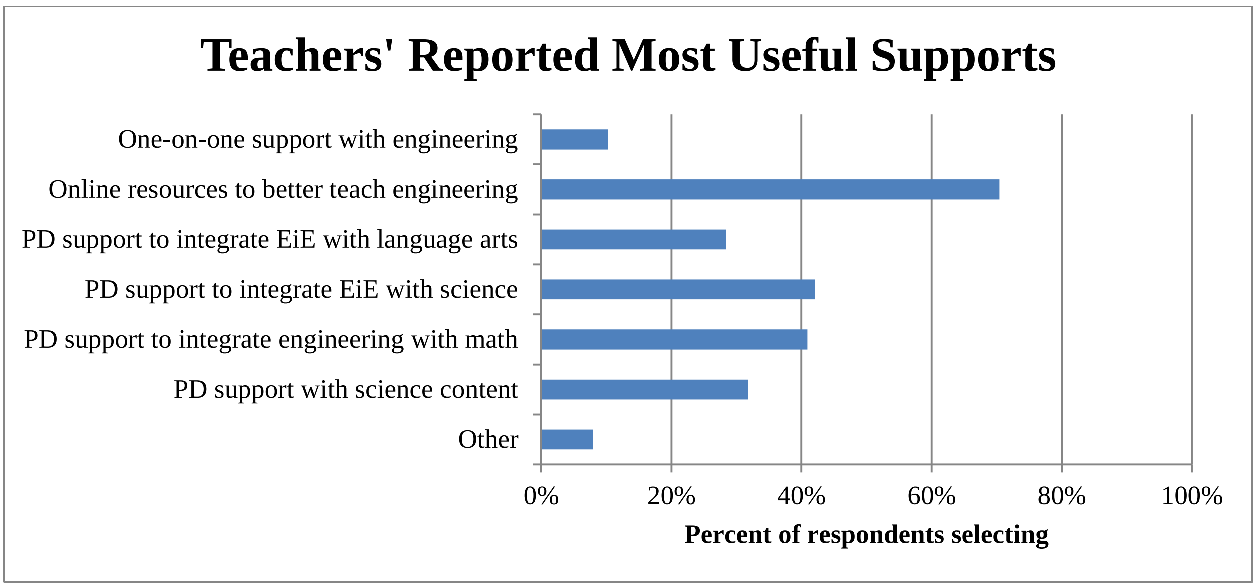

Figure 1. Responses to "Which of the following supports would be most useful to you? (Please select your top 3 choices)" on survey of EiE workshop participants (n=97)

After online resources for engineering education, the two areas in which teachers showed the most interest were integrating other subject areas with engineering—specifically math and science. On a following open-response question, respondents (n=45) indicated they would like support integrating engineering with math topics, including:

- "Extensions and stronger math connections"
- "More math integration lessons"
- "Integration with the Common Core State Standards"
- "Content connections to state standards"

Design of Workshop Key Components

In order to address the needs reported by teachers, we developed a two- day professional development workshop on the integration of math and engineering, specifically around the

Common Core State Standards for Math, titled "Linking the E & M in STEM". Several months before the workshop, we surveyed those teachers who had expressed interest in participating. We wanted to access their knowledge of and experience with CCSS. Responses in the initial surveys indicated that all workshop participants had a basic familiarity with the content in the CCSS, but that this level of familiarity varied (Table 1).

Table 1. Workshop Registrant Responses to "How familiar are you with the Common Core State Standards (CCSS) for Math?"

	Number	Percentage
I Currently implement math CCSS in class.	8	40%
I have experienced professional development about math CCSS.	3	15%
I have looked at math CCSS.	9	45%
Total	20	100%

Elementary math specialists confirmed that although elementary teachers follow CCSS as mandated by their districts, many do not have a full understanding of the critical areas and practices in the CCSS.[9, 10] Thus, the first component of our workshop needed to be: *Review of the CCSS for mathematics.*

The second component of our workshop stemmed from a second survey sent to the same group of teachers. In this survey, they shared a variety of methods for integration in their own classrooms. When asked how they integrated math with other subjects in their own classrooms, teachers' answers yielded diverse examples of integration (see Table 2 for examples).

Table 2. Sample Responses to "How have you integrated math with other subjects in your classroom?"

Examples of math integration
Building Lego cars and racing them. Students had to change their configuration of the race cars after races to try to increase speed or improve movability of the car.
Using the metric system as means of unit of measurement within science.
Measuring the lengths of various whales and comparing them during an ocean unit.
Using a read-aloud book focused on math and economics as well as having many math-based texts in the room (Greg Tang, Cindy Neuschwander, Jerry Pallota, etc.)
Students using the map scale to determine distances in social studies.

These examples suggest that there is no single way that teachers integrate math into other subjects in their classrooms. The depth and style of the integration varies greatly between teachers. According to Drake and Burns, educators often struggle with integration because "no clear formula for implementation exists, and no one definition describes the many variations found in practice."[11] Davison, Miller, and Metheny explain that "the expression 'integration of science and mathematics' is used in different ways throughout the science and mathematics education community…a pervasive problem is that integration means different things to different educators."[7] Considering these issues, we decided to model lessons in which math is used to meaningfully inform engineering design decisions. This would be the root of the second component of the workshop: *Modeling of classroom activities that highlight integration of engineering and math.* We wanted to model lessons that integrate math in which students utilize math to inform their engineering design. As previously mentioned, the National Council for Teachers of Mathematics supports the integration of math topics with other subjects.[8] We wanted participants to share a common integration experience to see that as their students engage in engineering challenges, there are many opportunities to use math to solve problems. Although some participants shared examples of math and engineering integration (e.g. using math to determine the success of Lego Cars), it seemed that many other teachers have not integrated math with design in this way. Therefore, we wanted to give participants more examples of how math is used as a key criterion for the students' design. We also wanted to encourage participants to see that the math skills and practices students employ while engineering are aligned with the CCSS.

It was not only important to model the type of integration we felt was most meaningful, but to guide teachers to understand these connections between math and engineering. To do so, we included a third component: *Discussion of how math adds value to engineering and how engineering adds value to math*. We wanted participants to share their ideas about integration before and after the modeling. This would help them to feel their ideas were appreciated and provide an opportunity to reflect on the modeling activities. Through our guided discussion, participants could exchange ideas with one another on what the integration of math and engineering brought to the subjects that study of each separately could not provide.

As an extension of this discussion, we also wanted participants to talk about examples of integration outside of the workshop experience. This would help reinforce what they experienced during the modeling, and allow them to talk about integration outside of their own subject areas. Participants would have the freedom to discuss lessons without fear of judgment by others. It would also help them come to some consensus on how to meaningfully integrate math with other subjects. To do so, we built in a fourth component: *Opportunities for teachers to think critically about examples of integration of math with other subjects.*

Finally, we wanted participants to plan for integration in their own classrooms. On the initial survey, teachers mentioned that they were interested in organizational tools for integration, so we would design such a tool and build time into the workshop experience to implement it. Thus, our final component was: *Time and resources for teachers to work with peers and plan integrated lessons.* It was clear that this feature should comprise a signifiant part of the workshop, because teachers rarely have time to collaborate with peers and could benefit from time outside of the class to plan. By having time to work with peers, teachers are able to gain and share effective ideas and teaching strategies. They could also have access to professional development providers as resources for reflecting on how to put their workshop learning into practice.

To help teachers plan this integration, we decided to offer concrete ideas on how to use engineering to teach standards and practices in CCSS. We completed a full review of our EiE curriculum, analyzing the lessons in several of the units to see how math concepts and skills are currently implemented. While the CCSS is not explicitly mentioned in the EiE curriculum, we found that math concepts and practices that appear in the CCSS are often utilized in the criteria and evaluation of students' designs. There are myriad opportunities for math integration in the engineering design process as students determine criteria, measure materials, and collect data to analyze the success of their designs. Table 5 presents several examples.

Table 3. Key Components of the Workshop

Number	Component
1	Review of the CCSS for mathematics
2	Modeling of classroom activities that highlighted integration of engineering and math
3	Discussion on how math adds value to engineering and engineering adds value to math
4	Opportunities for teachers to think critically about examples of integration of math with other subjects
5	Time and resources for teachers to work with peers and plan integrated lessons

The five components, described above and summarized in Table 3, were integrated into the structure of the workshop and served as the basis for workshop activities (Table 4).

Table 4. Workshop Activities and Key Components

#	Description of Workshop Activity	Key Component
1	Discussion: *What is meaningful integration of math?*	4 (other subject integration)
2	Activity: *What is engineering?*	2 (modelling of integration)
3	Activity: *EiE Unit: Designing Windmills*	2 (modelling of integration)
4	Activity: *Common Core Math Bingo*	1 (CCSS review)
Break between Day 1 and Day 2		
5	Activity/Discussion: *Examples of Math Integration*	3 (math/eng discussion) 4 (other subject integration)
6	Activity: *Integrated Windmills Lesson 3*	2 (modelling of integration) 3 (math/eng discussion)
7	Activity: *Common Planning Time*	5 (planning time)

Table 5. Example Opportunities for EiE Engineering and CCSS Standards Integration

EiE Unit	Description of Lesson	CCSS Practice or Standard	Possible Integrated Activity
Designing Model Membranes	Students investigate how different materials (screen, coffee filters, gravel and sand) act as water filters. They record how long it takes for ¼ cup of water to pass through each material.	3.MD: measure and estimate liquid volumes…using standard units 4MD & 5 MD: make a line plot to display a data set of measurements in fractions of a unit	Students measure the amount of water that passes through in a certain amount of time (e.g. ¼ cup water, ½ cup water). They then use the information about materials to make a line plot. They analyze the line plot in order to design their own model membranes.
Designing Parachutes	Students test how canopy size, suspension line length and canopy material affect the rate at which a parachute falls.	4.MD: Solve problems involving measurement and conversion of measurements.	Students record the number of seconds it takes for parachutes with varying canopy sizes, suspension lengths and materials to fall. They compare the data and discuss how the data proves which canopy size, suspension length and material could work the best in their own parachute design.
Designing Windmills	Students create sails and test their sails on a track. They improve their designs to see if they can go farther on the track.	3.NBT: Use place value understanding to round Whole numbers to nearest 10 or 100.	Students record the time it takes for their sail travelling on the track. When recording their times, will round to the nearest 10. Students discuss how rounding these numbers affects data and see if improvements to their design affect the data.
Designing Plant Packages	Students evaluate the cost of their plant package design using a materials pricing sheet.	2.MD: Solve word problems involving dollar bills, quarters, dimes, nickels, and pennies, using $ and ¢ symbols appropriately.	Students use the plant packages price sheet to solve problems with money. They then figure out how to improve their package by reducing the cost. Students could model the price of their package with actual coins.
Designing Water Filters	Students pour contaminated water into different filter materials to explore how well those filters clean the water and allow the water to pass through.	3.MD: Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories.	Students will represent the data they collect about filters in a bar graph. They can analyze the data by answering one- and two-step problems (e.g. "how much longer did the coffee filter take than the screen?") They then use this data to inform how they design water filters.

Results

Sample

We offered a pilot of this workshop for the first time in July of 2013 to gather data from participants about the activities, so as to refine them in order to best meet teachers' needs. More than 90 teachers expressed interest in the first pilot—an overwhelming response. Although 25 teachers registered for the workshop, the final attendance was 16 teachers. The low turn-out was due in large part to the timing of the workshop during summer break. Teachers who attended the workshop all taught in public schools in Massachusetts. Forty three percent of the teachers worked in low income schools (defined as over 40% of students receiving free and reduced price lunch). Forty three percent of the teachers taught in urban settings, 12% taught in rural settings, and 31% percent of teachers taught in suburban schools. We collected feedback through written surveys and a focus group that occurred immediately after workshop.

We offered a second pilot workshop in November of 2013, after making revisions to the workshop based on teachers' suggestions. Again, we had an overwhelming interest in this workshop, with more than 50 teachers expressing interest and 21 teachers attending. Teachers who attended this second workshop taught in a variety of schools in Massachusetts, including private, public, and charter schools. Thirty three percent of the teachers worked in low income schools (defined as over 40% of students on free and reduced price lunch). The teachers came in equal proportions from urban (33%), rural (33%), and suburban (33%) schools. We used the same surveys and focus group protocol from the first pilot to collect data from this workshop.

Results: Workshop Implementation

We began the workshop by asking teachers to explain what meaningful integration meant to them (Table 4, Activity #1). Their answers were largely abstract (Table 6), but a few mentioned "integration" in terms of actual lessons that they or colleagues had done with students in a variety of subject areas. Early in the workshop, teachers did not express how math should be used to inform students' design decisions. This concept would be further explored in several activities and addressed again on Day 2.

Table 6. Sample Responses to "What is Meaningful Integration?"

Meaningful Integration is…
Connecting Common Core Math and ELA
Fun
Hands-on
Connected to the real world
Connecting learning to problem-solving
Connected to future careers for students

For Activity 2, teachers worked in groups to design a tower out of index cards that held a small weight, an activity designed to help participants develop a common understanding of engineering (Table 4, #2). Throughout the activity, we modeled meaningful integration by employing math as a way to determine the criteria by which they would measure the success of their designs (implementing Key Component 2). For example, teachers charted their own heights and together used that data to determine the appropriate height of the tower. They then analyzed the data, calculating averages such as mean, mode, and median, as the basis for developing their criteria for the tower height. At the end of the activity, teachers reflected on the use of math in the engineering activity and on the relationship between the two disciplines.

Next, teachers explored engineering activities involving wind power (Table 4, Activity #3). Participants built sails and windmills out of simple materials to explore how they could best "catch the wind" with different materials and structures. These activities were introduced primarily as engineering lessons, and included very few math concepts. At the end of these activities, participants reflected on how math could be integrated with these engineering activities in their own classrooms. For example, participants recommended measuring how far their sails travelled using inches, and having students calculate the average distances their sails travelled. Teachers also suggested using data from how many weights the windmills lifted to create bar graphs, and measuring the areas of the windmill blades and making comparisons. This activity and discussion set the stage for returning to this same activity modeled with explicitly integrated math concepts on Day 2 to further address Key Component 2 (Table 4, #6).

Following the windmills activity, we introduced the participants to the CCSS for math by looking at the standards for a variety of grade levels. The teachers played an interactive game we developed to help solidify their understanding of the structure, content, and format of the standards (Table 4, #4).

On the second day, we discussed examples of integration of math with science and engineering and how math can add value to engineering activities (Table 4, #5). Participants then engaged in an altered version of the sail engineering activity from Day 1, which we had modified to more closely align with Common Core Math Standards for Grade 2 (Table 4, #6). Specific implementation of the math standards in the activity can be found in Table 7.

Participants created a line plot to analyze their data from Day 1 to evaluate the success of the sails they had designed. This activity modeled meaningful integration of math and engineering and demonstrated s that using math to evaluate the criteria for the success of a design can enhance an engineering activity (addressing Key Component 3).

To further model for teachers how we planned the lesson to integrate the CCSS with the engineering sails activity, we gave teachers a template that we had created and used for that purpose (template attached as Appendix A). This modeling prepared them to work in groups to plan integration of the CCSS they teach with an EiE engineering lesson for their own classrooms (Table 5, #7). We provided blank versions of the template to guide their discussion and planning. As a resource for engineering activities, we also provided teacher guides from the EiE curriculum. At various points in the planning time, we invited teachers to share their progress with the rest of the group and receive feedback.

Table 7. Windmills Activity Math Integration

Common Core Math Standard	Implementation in Activity
2.MD.1.2 - Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.	Participants choose a measurement device (ruler, yardstick, measuring tape) and measure and record how far their sails from Day 1 travel, measuring to the nearest whole unit.
2MD.4.2 - Measure the length of an object twice, using length units of different lengths for the two measurements; describe how the two measurements relate to the size of the unit chosen. Measure to determine how much longer one object is than another, expressing the length difference in terms of a standard length unit.	Participants are given the opportunity to improve and retest their designs. They measure how far their new designs travel using inches or feet, and compare the distances that the different sails travelled.
2MD.9 - Generate measurement data by measuring lengths of several objects to the nearest whole unit, or by making repeated measurements of the same object. Show the measurements by making a line plot, where the horizontal scale is marked off in whole-number units.	The whole group plots their results by posting 1" x 1" squares of the materials from which they made their sails on a line plot. The line plot is marked with inches and feet. Participants reflect on the line plot to make comparisons between units (inches and feet). They also compare the materials on the line plot and come to conclusions about which materials make the best and worst sails.

Results: Workshop Evaluation

Overall, feedback on the written surveys and during the focus group suggested the participants in the workshop had a positive experience. Teachers mentioned appreciation of several components of the workshop, including:

- modeling of engineering and math integration
- demonstration of measurement and data domains and how they are 'obviously' integrated with engineering.
- review of CCSS
- discussion of meaningful integration
- examples of integration of math with other subjects

Teachers' suggestions on how to improve the workshop focused largely on procedural issues, such as changing the time allotted for different activities and providing participants an opportunity to review EiE curricula prior to attending the workshop. They also had constructive recommendations around the facilitation of certain activities, but overall appreciated the structure of the workshop and the learning progression of the two days.

To examine the long-term effects of this first workshop, we surveyed the teachers who had attended six months later. Of the 16 attendees, 9 responded to the survey. Only a single teacher had taught the EiE curriculum at the time of the survey, so the survey was unable to provide sufficient evidence on how teachers actually integrated math with engineering based on the workshop. Teachers' open-ended responses on the survey, however, suggest that the workshop influenced their thinking about integrating STEM disciplines. Some illustrative examples:

- "This workshop greatly influenced me, as well as reinforced the idea that STEM thinking is pivotal in the classroom-this thinking is critical for children."
- "This workshop gave me ideas about how to integrate more in the areas of engineering and technology."
- "It was helpful to see … content and skills from different subject areas that were addressed and reinforced one another."
- "We got to … critically look at how to integrate a wide range of standards together and how to do so effectively." This respondent also mentioned that she appreciated "the part where we walked around and critically reviewed integrated science and math lesson plans for their effectiveness at targeting the standards."

Responses to the feedback forms and focus group for the second pilot were also positive. Participants valued the engagement with hands-on engineering activities that integrated with math. Several teachers said that the workshop helped them build their confidence in teaching math and engineering. Again, they appreciated the activity that reviewed the CCSS for math. They also said it was very useful to have time and resources to incorporate an engineering unit with their grade-level math. In this session, there were fewer suggestions as to how to improve the workshop, and participants seemed more satisfied with the structure and activities of both days of the workshop.

We surveyed these teachers three months later–of the 21 attendees, 13 responded to the survey. As in the previous pilot, teachers' comments suggest that the workshop had positive effects on their ideas about integration in the classroom.

- "I have become much more aware of how to integrate Math into all my science instruction. I have also created an Engineering Club across the district and currently work with 65 elementary students (Grade 3-6) for 1.5 hours across two days."
- "I have a new appreciation for linking math meaningfully. I have integrated measurement in our simple machines unit."

- “The examples of isolated vs integrated math were powerful.”
- “As a Curriculum Integration Specialist for my k-8 school, the workshop clearly reinforced a multitude of ways to easily integrate various content areas into project-based learning activities and engineering design challenges. I especially enjoyed meeting and collaborating with other professionals during the workshops.”

In addition to the open-ended question, teachers on both follow-up surveys were asked to rank the impact the workshop had on them. The majority of teachers reported that the workshop had a “great” or “slight” impact on how they integrated topics in their classrooms (see Figure 2). For the teachers who responded that the workshop did not make an impact, they stated that they already integrated subjects, could not integrate because they did not have the materials, or did not have support from their districts to do engineering with their students.

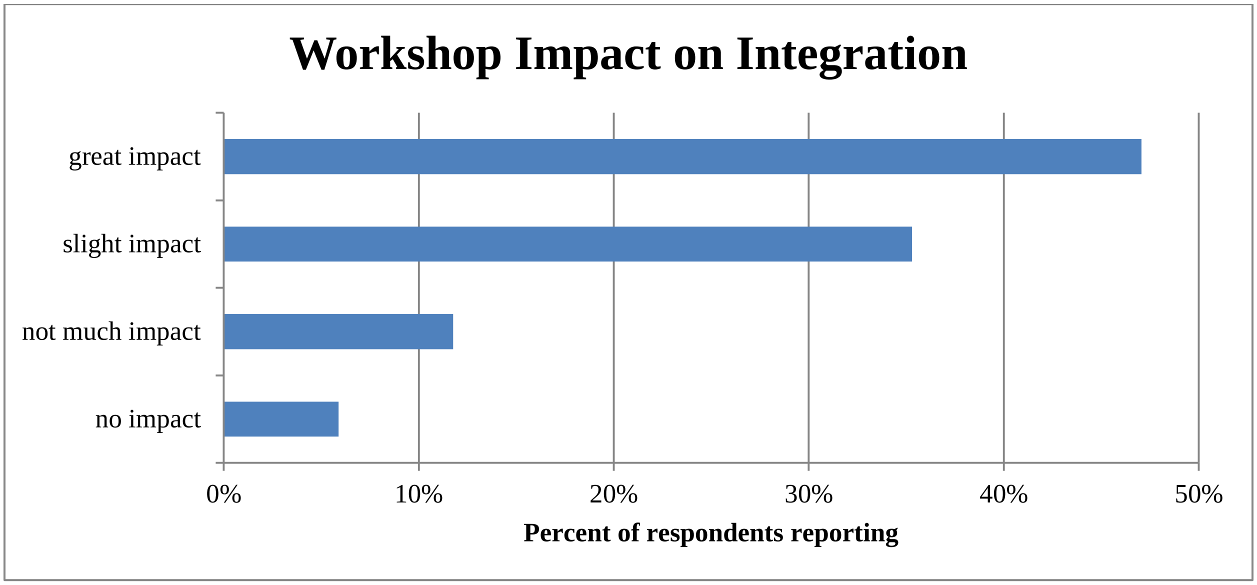

Figure 2. Teacher Responses to Follow-up Survey Question: “What impact did the Linking the E & M in STEM workshop have on whether or not you are integrating subjects?” (n=17)

Conclusions

The diverse types of data we gathered indicate that the workshop we developed had some meaningful impact on the teachers who participated. We hope to reach out to these teachers in the future to examine what other impact the workshop had. Additionally, we would like to collect the same types of data we have here when offering the workshop in the future.

It seems that teachers value the key components of the workshop. Without prompting, many teachers mentioned these components in their comments, referencing their appreciation that we addressed needs of teachers to have exposure to these types of activities and discussions. These key components, shown in Table 3, appear to have made a significant impact on teachers' confidence with CCSS and ability to integrate math and engineering in their own classrooms. We advocate that these components should be implemented and explored further by other professional developers as they seek to build teacher capacity to integrate math into engineering and other subject areas.

Integration of CCSS math with other subjects is becoming more and more prevalent for teachers, and this trend will likely continue. However, we also recognize that the primary challenge facing larger uptake of integrated math and engineering is the minimal opportunity that teachers have to teach engineering in their classrooms due to other subject area expectations being promoted as higher priorities, including the strong push for CCSS math. By taking part in this project, we were able to create an experience for teachers that met their needs for integration in a meaningful and relevant way. We anticipate that demand for workshops such as these will increase in the future, and we will soon offer this workshop to many schools and districts in Massachusetts as well as nationally. We hope others might build off of our methods and create similar experiences to help teachers integrate CCSS in meaningful, relevant ways.

It is clear that STEM integration is continuing to grow as a major focus in American education. This workshop, while a valuable tool for improving education, is a small part of a much larger movement. This is an exciting time for education as we see traditional classrooms transitioning into places where students are engaged in learning, and where students see the interdisciplinary value of mathematics. We look forward to continuing to work with teachers to refine mathematics and engineering integration to reinforce for students that these subjects are key components of their world.

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APPENDIX A: Integration Template

Idea #	EiE Lesson # and P. #	Description of EiE Lesson	Common Math Standard, Cluster or Practice	Related Integrated Activity or Idea	Time needed	Notes
	Lesson 3 Example: p. 78	*Students create sails and test their sails on a track. They improve their designs to see if they can travel farther on the track.*	*3.NBT: Use place value understanding to round Whole numbers to nearest 10 or 100.*	*3.NBT: Students will record the time it takes for their sail travelling on the track. When recording their times, will round to the nearest 10. Discuss how rounding these numbers affects data.*	*1 class period*	