A state wide professional development program in engineering with science and math teachers in Alabama: Fostering conceptual understandings of STEM

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Subject/Problem

The Robotics and Engineering Education-Fostering the Conceptual Understanding of Science (RE²-FoCUS) project is a 3-year teacher professional development (TPD) initiative designed to stimulate project-based STEM education throughout the state of Alabama. The immediate purpose of the project is to increase the number of middle school students in Alabama who participate in STEM-centered, project-based learning activities and programs that promote teamwork, problem solving, critical thinking skills, and authentic, real-world situations. Teacher professional development, when it is sustained, intensive, and content focused, has the potential to significantly and positively impact not only teacher performance, but student learning (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). Through a targeted and intensive professional development experience, middle school science and math teachers in this study learned how to implement engineering design into their existing science and math classes. The long-term goal of this intervention is to positively impact student achievement in math and science in the state of Alabama. The need for improved student achievement in this state is dire. In 2011, Alabama 8th grade students ranked 48th in the nation on the National Assessment of Educational Progress (NAEP) science test (IES, 2011), and Alabama ranked 41st in 2011 on the science portion of the ACT with an average score of 20.1 (ACT, 2011). There is much room for improvement.

Engineering design-based curriculum has been demonstrated to positively affect students’ attitudes toward science in addition to improving their science content knowledge when the curriculum is specifically designed to target science concepts, and when the design challenge directly utilizes science concepts (Schnittka, 2011). However, teachers must first overcome
implementation hurdles, which include a lack of domain-specific content knowledge, a lack of self-efficacy, and a lack of experience using engineering design as a vehicle for science instruction (Yasar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006; Yoon, Kong, Diefes-Dux, & Strobel, 2013).

During the first year of the initiative, teachers across the state participated in TPD designed to provide foundational training in implementing engineering design in their classrooms. Using Save the Animals STEM curricula, which are engineering design-based modules developed by Schnittka (2009, 2012), teachers learned the fundamental science and mathematics associated with alternative energy resources, energy transfer, and energy sustainability through problems related to environmental issues that affect animals. During years two and three of the initiative, teachers who implement the Save the Animals curricula with their students will be invited to participate in a second professional development opportunity focused on robotics design, construction, operation, and computer programming skills. Teachers will also learn science and math content applications related to optimizing robotic function such as simple machines, motion, force, power, along with the basic algebra and trigonometry used in applying these concepts to real situations.

**Literature Review**

In the past decade, there have been only a few research studies that have investigated the importance of providing professional development in engineering education as a way to bolster STEM understanding for K-12 students. Although there is a general agreement in the literature about principles for effective teacher professional development (Garet et al., 2001; Loucks-Horsley et al., 2003), few studies have investigated the role of engineering and its effect on STEM instruction and STEM learning. In the past year, through curriculum development,
implementation through funded projects, and subsequent research, the authors have obtained a better understanding of how engineering design-based curriculum can be effective in increasing teacher STEM understanding and increasing teacher self-efficacy and attitudes about engineering. In this section we briefly describe the literature that provides the best support for our methods, research, and subsequent findings.

In their work, Zarske et al. (2004) emphasized not only the importance of the engineering design-based curricula itself but the added benefit of having teachers work together to teach each other how to implement the curricula. These results helped determine that the “teachers teaching teachers” model of professional development was effective in promoting engineering design-based curricula implementation at the K-12 level.

Cullum et al. (2008) emphasized the importance of engineering in K-12 curriculum and researched the factors that indicated which major engineering concepts should be included in science curricula. They emphasized the importance of engineering in developing future science curricula, and not unlike our study, they understood the importance of incorporating engineering to satisfying state and national education standards. They stressed the importance of devoting a significant amount of time to helping teachers with science content prior to the engineering challenge. They also stressed the importance of framing the design challenge within an engineering framework emphasizing “constraints, optimizations, and predictive analysis… prior to, and during, hands on activities” (p. 15).

In a study similarly structured to our Save the Animals STEM curriculum, High et al. (2009) investigated the impact of an interdisciplinary problem-based learning approach using DET (Design, Engineering and Technology) activities in a professional development workshop for teachers. The authors documented and catalogued teachers’ perceptions of the value of
engineering in K12 education before and after the workshop. They found substantial positive gains in teachers’ perception of the value of DET activities when teachers were introduced to DET using problem-based learning approaches.

Powers et al. (2010) discussed the importance of having access to the newest learning strategies and teaching models as well as access to working professionals in the science fields to help K-12 teachers through professional development workshops to convey content knowledge to their students. The researchers compared pre/post tests of attitudes, science content knowledge, and behavior of teachers who attended professional development workshops run by professional educators and scientists from the university and found significant gains in both attitudes and knowledge.

Wang et al. (2011) investigated the beliefs, classroom practices, as well as perceptions of engineering in a professional development workshop integrating STEM practices. Similar to our Save the Animals STEM curriculum, Wang et al. (2011) recognized the importance of the teachers’ perceptions of and attitudes toward engineering and its effect on student understanding of these concepts. Through teacher interviews after the workshop, authors found supporting evidence that professional development workshops are essential to make STEM integration effective and sustainable.

Donna (2012) developed and outlined a research-based model for design professional development for teachers that could potentially link engineering-based activities with other STEM concepts. Comparing our Save the Animals STEM curriculum and associated professional development to the components of the model developed by Donna (2012) allows for much congruence. Most of the steps discussed by Donna (2012) have been addressed by our model of PD.
1. Explore prior knowledge related to engineering and relationships between domains,
2. Develop basic knowledge of engineering,
3. Engage in cooperative engineering design activity, and
4. Reflect on activity as both learners and STEM educators (p.3).

The only component Donna (2012) included that we did not was the formal development of professional learning communities after PD concludes. While this took place informally in our study due to the statewide AMSTI model, it was not a formal part of the design.

Yoon, Diefes-Dux, and Strobel (2013) determined that engineering teacher professional development was extremely effective at improving the participating elementary teachers’ knowledge of the engineering design process as well as changing teacher perceptions of integrating design, engineering and technological concepts. Through examining the first-year effects of a professional development program, teachers significantly increased their knowledge about the engineering design process (EDP) and some perceptions of design, engineering and technology (DET).

Building upon all this previous work with teacher PD in engineering, the current study involves training pairs of math and science specialists from a state network to teach groups of science and math teachers in their regions. During three-day hands-on workshops that target key scientific and mathematical concepts in the context of engineering design challenges, teachers work in teams on design projects that involve constraints, optimization, and predictive analysis. In this study, we measure not only changes in science content knowledge, but changes in attitudes toward engineering and changes in self-efficacy to teach engineering.

**Theoretical Framework**

Learning is not an individual, isolated process; it involves the interchange of ideas
between teacher and student and among peers. Social interchanges support the manners in which students construct meaning about objects and concepts. The *Save the Animals* STEM curriculum is formulated around collaborative learning, which is the basis for a dominant theory of how people learn—social constructivism.

Lev Vygotsky (1978), the founding father of social constructivism coined the idea that social interaction along with critical reflection fosters the learning process. This theory does not support the notion that learning is merely an internal process, nor is it passive. Bryceson (2007) formulated that culture and an individual’s surroundings are also key instruments in formulating understanding and deep learning. Before the learning process can even begin, there must be a sense of community established, a teacher awareness of student backgrounds, and a teacher awareness about various approaches to bringing experiences to the classroom. Also within the framework of social constructivism, Vygotsky formulated the idea of the zone of proximal development (ZPD), defined as “the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (1978, p.86). This idea banks on the notion that students, with the assistance of teachers or peers, can perform tasks together that would have been difficult, or even impossible to undertake on an individual level. Often students will learn easiest within this zone when others are involved (Kalina and Powell, 2009).

This teacher professional development subscribes to all of the aforementioned ideas. In a collaborative manner, teachers design, build, and test devices that model real-world scenarios. The aim of the workshop is to take what prior knowledge the teachers possess, and build upon that knowledge using basic mathematics and scientific principles. Scaffolding, according to
Kalina and Powell, follows Vygotsky’s (1962) thoughts that the process of pushing students to the next level of understanding is done through the guidance of teachers and other peers. Participants in the three-day workshop begin with basic secondary science and math concepts, and through coaching and peer interaction, construct devices that encompass higher order thinking skills. These skills, in turn, are intended to be taught to middle and high school students. This workshop also involves teachers from diverse backgrounds and varying degrees of content knowledge. However through teacher interaction and coaching, all should complete the workshop with higher levels of understanding.

**Design/Procedure**

With support from the Alabama State Department of Education, the team utilized the existing network and infrastructure of the statewide Alabama Math Science and Technology Initiative (AMSTI) network in a “train-the-trainer” model to recruit and provide PD for 140 middle school math and science teachers during summer 2013. The state of Alabama is divided into 11 regions, with each region serving the local schools. During summer 2013, 16 math and science middle grades specialists (trainers) from 9 of the 11 regions participated in a three-day training workshop on two of the *Save the Animals* curriculum modules. The *Save the Animals* modules were designed to encourage youth to recognize how their behaviors at home affect animals the world over. They explore science concepts, environmental issues affecting animals, and engage in engineering solutions to remediate the problems, thus saving the animals.

Following the workshop, trainers in each of the nine regions recruited 11-23 middle school math and science teachers from their service regions and conducted separate three-day workshops using the same curriculum modules. These statewide satellite workshops were observed by project staff in order to assess fidelity of implementation and offer assistance. In the
first curriculum module, *Save the Penguins*, the trainers taught basic thermodynamics (e.g. mechanisms of heat transfer, insulation, and energy efficiency) through a hands-on engineering design project where teachers designed and built miniature, thermally insulated houses for penguin-shaped ice cubes. See Figure 1.

In the second curriculum, *Save the Sea Birds*, teachers learned basic energy transformation principles and fundamental Newtonian mechanics through an engineering challenge that required them to design and build solar powered mass transportation vehicles. See Figure 2.
In both modules, teams of teachers worked within constraints, used predictive analysis, evaluated the effectiveness of their design decisions, and then used the re-design phase of the engineering design process to optimize their final product. They explicitly discussed how the scientific principles were used in the design process. Predictive analysis calls for using math and science to make informed decisions before constructing a model or prototype. Predictive analysis is a crucial component of the engineering design process; it is often the first component to be left out of K12 engineering design-based curriculum (Gattie & Wicklein, 2007; Katehi, Feder & Pearson, 2009).

Evaluations of science content knowledge and attitudes were administered to the 16 trainers and a total of 140 teachers prior to and after the trainer workshop and the separate teacher workshops that followed. The primary qualitative instrument was an open-ended questionnaire developed by the researchers, which was administered prior to and after the
workshops. Other instruments were a valid and reliable multiple choice instrument that assessed conceptions about heat transfer called Heat Transfer Evaluation (HTE) (Schnittka & Bell, 2011), a valid and reliable multiple choice instrument that assesses conceptions about force, motion, and energy called Force, Motion, and Energy (FME) (Schnittka, 2012), the Likert-scale Teaching Engineering Self-Efficacy Scale (TESS) (Yoon, Evans, & Strobel, 2012), and a valid and reliable Likert-scale instrument that assesses Attitudes Toward Engineering (ATE) (Schnittka & Bell, 2011).

Research questions are: 1) What are teachers’ attitudes toward engineering and self-efficacy to teach engineering before and after the PD? 2) How competent are teachers with the science content before and after the PD? 3) What impact does the curriculum have on classroom students’ engagement and motivation during implementation?

Findings and Analysis

Outcomes: Teacher self-efficacy and attitudes toward engineering at nine sites.

Analyses were performed for nine of the 11 sites, comparing the Likert-scale scores of teacher self-efficacy for teaching engineering (a personal belief in their ability to incorporate design activities into their classroom) before and after workshop participation. The instrument, Teaching Engineering Self Efficacy (TESS) developed by Yoon, Evans, & Strobel (2012) was used for this analysis. The TESS includes items such as, “I can discuss how engineering is connected to my daily life” and “I can promote a positive attitude toward engineering learning in my students.” Results from a paired sample t-test showed that engineering self-efficacy increased significantly ($p < 0.05$) for all nine teacher groups following the professional development (see Table 1).
Sites Eta and Theta had the highest posttest scores of self-efficacy, and the highest percent increase. Site Beta had one of the lowest posttest scores, and the lowest increase in self-efficacy. The research team is working to investigate what may have contributed to those differences.

Comparisons were also made on the Likert-scale scores of “attitudes toward engineering” (which are teachers’ attitudes towards the engineering profession) before and after the PD using the ATE instrument (Schnittka & Bell, 2011). The ATE includes items such as, “Engineers design things that are practical and useful” and “Engineering skills are useful in everyday life.” Results from a paired sample t-test showed significant positive changes in teacher attitudes toward engineering in 7 of the 9 groups after attending the workshops (see Table 2).

Table 1. Pre and post-test means, standard deviations, and statistical significance of self-efficacy (138 possible points)

<table>
<thead>
<tr>
<th>Site</th>
<th>Pretest</th>
<th>Posttest</th>
<th>% Increase</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Alpha (n = 13)</td>
<td>100.6 (SD = 13.55)</td>
<td>115.7 (SD =11.30)</td>
<td>10.0</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Beta (n = 19)</td>
<td>106.7 (SD = 10.88)</td>
<td>113.1 (SD = 11.25)</td>
<td>4.6</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Gamma (n =11)</td>
<td>106.3 (SD =13.89)</td>
<td>122.7 (SD =10.17)</td>
<td>8.0</td>
<td>0.002*</td>
</tr>
<tr>
<td>Site Delta (n = 15)</td>
<td>106.8 (SD = 10.83)</td>
<td>117.2 (SD =14.70)</td>
<td>7.5</td>
<td>0.023*</td>
</tr>
<tr>
<td>Site Epsilon (n = 14)</td>
<td>92.85 (SD = 13.88)</td>
<td>109.0 (SD = 14.92)</td>
<td>11.6</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Zeta (n = 17)</td>
<td>105.1 (SD = 18.18)</td>
<td>118.6 (SD =10.45)</td>
<td>9.8</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Eta (n = 11)</td>
<td>105.6 (SD = 15.04)</td>
<td>123.8 (SD =10.66)</td>
<td>13.2</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Theta (n = 23)</td>
<td>105.6 (SD = 16.10)</td>
<td>123.8 (SD =12.88)</td>
<td>13.2</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Iota (n = 16)</td>
<td>107.6 (SD = 14.68)</td>
<td>120.6 (SD =10.65)</td>
<td>9.5</td>
<td>&lt; 0.001*</td>
</tr>
</tbody>
</table>

* = statistically significant
Table 2.
*Pre and post-test means, standard deviations, and statistical significance of attitudes*
(55 points possible)

<table>
<thead>
<tr>
<th>Site</th>
<th>Pretest</th>
<th>Posttest</th>
<th>% Increase</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Alpha (n = 13)</td>
<td>47.15 (SD = 4.45)</td>
<td>49.46 (SD = 4.9)</td>
<td>4.2</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Beta (n = 18)</td>
<td>45.9 (SD = 2.83)</td>
<td>47.6 (SD = 3.34)</td>
<td>3</td>
<td>0.04*</td>
</tr>
<tr>
<td>Site Gamma (n = 11)</td>
<td>47.18 (SD = 2.82)</td>
<td>49.5 (SD = 3.67)</td>
<td>4.2</td>
<td>0.018*</td>
</tr>
<tr>
<td>Site Delta (n = 15)</td>
<td>46.7 (SD = 3.12)</td>
<td>49.4 (SD = 2.89)</td>
<td>4.8</td>
<td>0.013*</td>
</tr>
<tr>
<td>Site Epsilon (n = 14)</td>
<td>46.14 (SD = 4.2)</td>
<td>47 (SD = 4.09)</td>
<td>1.5</td>
<td>0.396</td>
</tr>
<tr>
<td>Site Zeta (n = 17)</td>
<td>44.2 (SD = 3.73)</td>
<td>48.52 (SD = 3.73)</td>
<td>7.8</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Site Eta (n = 11)</td>
<td>49 (SD = 2.89)</td>
<td>47.8 (SD = 5.81)</td>
<td>-2.1</td>
<td>0.47</td>
</tr>
<tr>
<td>Site Theta (n = 23)</td>
<td>46.08 (SD = 4.28)</td>
<td>50 (SD = 3.17)</td>
<td>7.1</td>
<td>0.002*</td>
</tr>
<tr>
<td>Site Iota (n = 16)</td>
<td>47.6 (SD = 2.68)</td>
<td>49.6 (SD = 3.48)</td>
<td>3.7</td>
<td>0.008*</td>
</tr>
</tbody>
</table>

* = statistically significant

Teachers at Site Epsilon and Site Eta did not demonstrate an increase in their attitude toward engineering. With 55 points possible, all sites reported high scores, which indicates that a ceiling effect may have been at work. There was not much room for growth. Since teachers self-selected to participate in an engineering PD, it is not unexpected that their attitudes toward engineering would be high to start with. When questions were examined individually, teachers significantly increased their agreement with the statement, “Engineering would be a highly interesting profession for my students” while they significantly decreased their agreement with the statement, “Engineers spend most of their time doing complex mathematical calculations.”

In addition to this analysis, we also investigated the possible effects of the individual trainings as a factor that could influence the results on self-efficacy. Qualitative analysis of surveys and the effect of trainer attitudes on teacher attitudes will be explored further.
**Outcomes: Teacher content knowledge at nine sites**

Pre- and post-assessments covering topics including heat transfer, force, motion and energy were administered. There were 12 multiple choice items on the Heat Transfer Evaluation and 17 multiple choice items on the Force Motion and Energy assessment and scores were converted to percentages. The HTE includes items such as, “You have a can of soda in your lunchbox that you want to keep cold. Which material will work best to keep it cold and why?” and “Why do we wear sweaters in cold weather?” The FME includes items such as, “What is the best definition of energy?” and “A car with a full tank of gasoline is driven until it runs out of gas. What happened to the gasoline's energy?” Paired sample t- tests were used to calculate the difference between the pre- and post- scores by training site. The gains from pre- to post-test on the heat transfer assessment were statistically significant at each of the 9 sites analyzed. Gains from pre- to post-test for the force, motion, and energy assessment were significant at each of the 9 sites analyzed. See Table 3 and 4 for means and percent increase and significance.

**Table 3.**
*Pre and post-test results on the heat transfer assessment.*
(100 points possible)

<table>
<thead>
<tr>
<th>Site</th>
<th>Pretest</th>
<th>Posttest</th>
<th>% Increase</th>
<th>Significance, p</th>
<th>Effect Size, r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Alpha (n = 13)</td>
<td>66.03</td>
<td>91.67</td>
<td>38.83</td>
<td>&lt; 0.001*</td>
<td>0.83</td>
</tr>
<tr>
<td>Site Beta (n = 20)</td>
<td>60.42</td>
<td>76.32</td>
<td>26.32</td>
<td>0.001*</td>
<td>0.67</td>
</tr>
<tr>
<td>Site Gamma (n = 11)</td>
<td>51.51</td>
<td>83.33</td>
<td>61.77</td>
<td>&lt; 0.001*</td>
<td>0.84</td>
</tr>
<tr>
<td>Site Delta (n = 15)</td>
<td>63.02</td>
<td>83.85</td>
<td>33.05</td>
<td>&lt; 0.001*</td>
<td>0.69</td>
</tr>
<tr>
<td>Site Epsilon (n = 13)</td>
<td>55.13</td>
<td>82.69</td>
<td>49.99</td>
<td>0.001*</td>
<td>0.76</td>
</tr>
<tr>
<td>Site Zeta (n = 17)</td>
<td>68.14</td>
<td>82.35</td>
<td>20.85</td>
<td>0.002*</td>
<td>0.78</td>
</tr>
<tr>
<td>Site Eta (n = 11)</td>
<td>49.24</td>
<td>72.73</td>
<td>47.71</td>
<td>0.004*</td>
<td>0.69</td>
</tr>
<tr>
<td>Site Theta (n = 23)</td>
<td>62.68</td>
<td>83.7</td>
<td>33.54</td>
<td>&lt; 0.001*</td>
<td>0.76</td>
</tr>
<tr>
<td>Site Iota (n=16)</td>
<td>76.04</td>
<td>95.31</td>
<td>25.34</td>
<td>&lt; 0.01 *</td>
<td>0.56</td>
</tr>
</tbody>
</table>

* = statistically significant
Table 4.
Pre and post-test results on the force, motion, and energy assessment.
(100 points possible)

<table>
<thead>
<tr>
<th>Site</th>
<th>Pretest</th>
<th>Posttest</th>
<th>% Increase</th>
<th>Significance, p</th>
<th>Effect-size, r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Alpha (n = 13)</td>
<td>62.44</td>
<td>81.00</td>
<td>29.72</td>
<td>&lt; 0.001*</td>
<td>0.87</td>
</tr>
<tr>
<td>Site Beta (n = 19)</td>
<td>57.89</td>
<td>76.16</td>
<td>31.55</td>
<td>&lt; 0.001*</td>
<td>0.88</td>
</tr>
<tr>
<td>Site Gamma (n = 10)</td>
<td>54.1</td>
<td>73.53</td>
<td>35.87</td>
<td>&lt; 0.001*</td>
<td>0.79</td>
</tr>
<tr>
<td>Site Delta (n = 15)</td>
<td>65.81</td>
<td>80.51</td>
<td>22.34</td>
<td>&lt; 0.001*</td>
<td>0.76</td>
</tr>
<tr>
<td>Site Epsilon (n = 13)</td>
<td>64.71</td>
<td>76.02</td>
<td>17.48</td>
<td>0.003*</td>
<td>0.78</td>
</tr>
<tr>
<td>Site Zeta (n = 17)</td>
<td>62.63</td>
<td>78.20</td>
<td>24.86</td>
<td>&lt; 0.001*</td>
<td>0.75</td>
</tr>
<tr>
<td>Site Eta (n = 12)</td>
<td>60.43</td>
<td>75.94</td>
<td>25.66</td>
<td>0.005*</td>
<td>0.75</td>
</tr>
<tr>
<td>Site Theta (n = 23)</td>
<td>56.01</td>
<td>76.98</td>
<td>37.44</td>
<td>&lt; 0.001*</td>
<td>0.76</td>
</tr>
<tr>
<td>Site Iota (n=16)</td>
<td>68.38</td>
<td>85.29</td>
<td>24.73</td>
<td>&lt; 0.01*</td>
<td>0.58</td>
</tr>
</tbody>
</table>

* = statistically significant

For all sites, there was an overall increase of 36% ($r = 0.82, p < 0.001$) on the heat transfer assessment, and an overall increase of 26% ($r = 0.84, p < 0.001$) on the force, motion, and energy assessment. Given the results of the pre- and post- science content assessments, the significant increase in scores from pre- to post-, on both assessments, the research question related to the impact of the professional development on science content knowledge is definitively answered. The professional development significantly increased teachers’ science content knowledge. These findings, in turn, could have profound effects on student achievement across the entire state, if the curriculum is implemented properly.

Teacher exit survey – results from open response questions:

Teachers were invited to complete an exit survey after the workshops that included several open-response questions related to their workshop experience and their intentions for future use of the curriculum with their students. A total of 121 teachers responded to the survey. Teachers indicated their interest in using the curriculum with their students during the upcoming school year for a variety of reasons that largely focused on the hands-on, inquiry-based nature of
the curriculum. Typical responses to the question “Will you use this curriculum? Why or why not?” included,

“Yes - I think my students would benefit cognitively from this experience.”

“Yes, hands-on, Inquiry-based learning; Real world connections.”

“Yes, I feel like these are the types of lessons that should be developed and used to correlate and reach the goals of CCR and NGSS.”

“Yes. I think the real world application of concepts taught in my math class will be a great addition to my teaching.”

“Yes, to encourage students to consider engineering degrees.”

“Absolutely. The material is directly related to my COS objectives and is grade level appropriate.”

“Yes. It's a fantastic way to encourage my students, and it will help them see how engineering relates to all aspects of life.”

Three teachers indicated they ‘might’ implement the curriculum in their classrooms. In one case, an 8th grade math teacher reported the curriculum would have to be used with an advanced class and only after completing the required standards. In a second case, an elementary teacher reported uncertainty about whether the curriculum would be appropriate for 5th and 6th grade students. In a third case, an 8th grade math teacher provided positive feedback about the curriculum but reported that she would share it with the science teacher at her school, implying she did not plan to implement the curriculum with her math students. In total, an overwhelmingly large number of teachers who responded to the survey question (117 out of 120, or 97.5%) indicated their intentions for implementing the curriculum with their students during the upcoming school year.

*Results from pre- and post-test on teachers’ self-evaluation of their knowledge of key workshop topics:*
Analyses were performed for teachers from 7 of the 11 sites (n=95) comparing Likert-scale scores of teachers’ self-evaluation of their experience and knowledge of twelve specific topics (engineering design cycle, heat transfer, convection, conduction, energy, radiation, friction, electricity, force, inquiry, constructivism, and alternative conceptions) before and after workshop participation. A minimum score of 12 on the evaluation would indicate a teacher’s lack of confidence in their knowledge of these topics, whereas a maximum score of 60 would indicate a high level of confidence in their knowledge. Teachers rated themselves an average score of 32.3 on the pre-test and 46.8 on the post-test, a gain of 14.5 points following professional development. Results from a paired samples t-test showed that teachers’ overall self-reported confidence level in their knowledge of engineering and science related topics increased significantly ($p < 0.001$) following the professional development. Only two teachers reported negative gains in their confidence level following the professional development. In general, elementary teachers and middle school math teachers showed the greatest gains in confidence (15.5 and 17.3 points, respectively), while middle school science teachers showed the least gains (12.2 points), although middle school science teachers did report the highest pre- and post-test scores on science content of any group.

*Teacher interviews after using the curriculum with their students*

To date, 44 teachers across the state have reported using one or both of the curriculum modules with their students. We have collected surveys from 25 of these teachers about their goals for using the curriculum, their perceptions of student learning and engagement during implementation, their thoughts about the design challenges, and other reactions to teaching with engineering design. We are still collecting surveys from teachers, and plan to have a full analysis of their responses by the end of the school year.
For the current study, we are interested in determining if the curriculum has had an impact on classroom students’ engagement and motivation in STEM disciplines. In response to the question, “Did you see an increase in student engagement when you used this curriculum”, 80% of teachers reported a positive increase, 12% did not respond to the question, and 8% (2 teachers) reported a high student engagement, but no more than typical. Both “neutral” teachers indicated ‘business as usual’ because of their frequent use of hands-on, inquiry-based activities through the AMSTI program. AMSTI-active teachers reported the following:

“Engagement is about the same as normal in my class but we use AMSTI on a daily basis and the students love the hands-on discovery with it (Teacher 13, Site Delta)”.

“Student engagement was about the same for me. We are an AMSTI school so my students are very familiar with hands-on activities. We do 2-3 lab activities a week so it was just an added bonus to get to do this one (Teacher 11, Site Delta)”.

Of the teachers who responded to the post-implementation survey, none reported a decrease in student engagement. Below is a representative sample of the 20 teacher responses indicating increased student engagement during Save the Animals classroom implementation.

“The students were definitely engaged. I believe there was an increase because of the group work and hands on activities (Teacher 13, Site Alpha)”.

“Yes I saw an increase. I think the activities got the kids excited about math and then they were looking for ways that they could apply what was being learned at home (Teacher 4, Site Beta)”.

“Almost all students maintained full engagement during the project. This is evidenced by the creative storyboards from my artists, the in depth explanations by my analytical thinkers, and the numerous questions by my vocal students. I have never been so busy in any project with my students (Teacher 1, Site Gamma). ”

“Most of the students have never had that type of instruction before this unit. They were used to being told what to do and how to do it. So giving them some freedom to make mistakes was scary to them. The test results from the previous to the end served as some of the evidence and their enjoyment served as another part of the evidence. They really did not want to stop when I told them that we were finished (Teacher 6, Site Zeta). ”
“I believe it brought the concepts to life. The students related to all 3 types of heat transfer. It was great seeing how they started thinking and talking like engineers by the end of the kit (Teacher 14, Site Beta).”

“All the students were actively engaged. They enjoyed doing the hands on experiments and learning by doing. One piece of evidence is that we were working on a particular lab and got so involved in it that the class went over by 10 minutes and no one noticed (Teacher 11, Site Eta)”.

In response to the question, “Did you see an increase in student motivation”, 72% of teachers reported a positive increase, 12% were neutral, 16% provided no response, and none reported a decrease in motivation. Below is a representative sample of teachers’ responses.

“Yes, there was an increase in student motivation. If for any reason we had to miss class, the students were extremely disappointed. They were always eager to begin class just to see what we were going to do next (Teacher 13, Site Alpha).”

“Yes. The students seemed more motivated because I presented them a real world problem and had them solve it. This is exactly what kids want to do in school, and exactly what employers want kids to be able to do (Teacher 1, Site Gamma).”

“The students looked forward to the activities and they discussed their work with their parents on a regular basis. The feedback from the parents and students was positive. Students did not want to miss a class (Teacher 4, Site Alpha).”

“The design challenge was what motivated the students. It also forced them to think as a team (Teacher 10, Site Delta).”

“This was taught to an Enrichment class- STEM team- of about 20 7th and 8th graders. The “Save the Penguins” concept really hooked them from the beginning. So much so, they took their team yearbook picture with stuffed penguins (Teacher 11, Site Zeta).”

Overall, teacher responses provided substantial qualitative evidence of increased student engagement and motivation during Save the Animals curriculum implementation, substantiating the research question related to student impact.

**Contribution to the teaching and learning of science and engineering**

In summary, by participating in three days of professional development, science and math teachers who engaged in curriculum that reinforced the following - engineering design, inquiry
and experimental design, physical science concepts and applied mathematics - made significant gains in science content knowledge and attitudes toward engineering and self-efficacy to teach engineering. Teaching science and mathematics through engineering design is a relatively new innovation for the K-12 classroom and few teachers are adequately prepared for it (Hynes, 2012). A large movement is underway to provide teachers with effective professional development opportunities that will better enable them to integrate engineering into their classrooms (Capobianco, Mena, & Diefes-Dux, 2011), however, little is known about what constitutes highly effective professional development in K-12 engineering education. However, as a result of this project, teachers who had limited or no experience using engineering design in their classrooms reported increased attitudes and self-efficacy, and increased science and engineering knowledge and skills. Now that they have gained confidence, these teachers across the state may be more likely to integrate other STEM projects and ideas into their formal teaching practices. As the Next Generation Science Standards are adopted by states, engineering will be a required component at every grade level. Results from this statewide study will inform the ASEE community about best practices to engender significant gains in science understandings, and attitudes toward engineering, and self-efficacy to teach engineering through engineering design activities.
References


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