

Evaluating the Risk: In an Age of High Stakes Testing, Should Teachers Integrate Engineering Design into Traditional Science and Math Courses?

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Introduction

Projects employing engineering design principles are known to promote 21st century skills development among students. With an increased focus on STEM in primary and secondary curricula and the importance of 21st century skills for students to solve real world problems, K-12 educators are being encouraged to expose students to engineering design principles. However, in an age of standardized testing and high stakes accountability, many traditional math and science teachers are reluctant to include engineering design projects in courses where students will take statewide assessments or AP exams. This reluctance may stem from teachers' perceived burden of integrating these time-consuming principles into existing curricula. As a result, engineering design is often relegated to engineering elective courses or courses not subject to high stakes testing or required academic standards. This is particularly true in states that have not formally adopted the Next Generation Science Standards. By modeling and assisting teachers in integrating engineering design using course-specific challenges, this perceived burden may be mitigated and student achievement results may verify the merits of engineering design integration.

This paper examines the impact of an NSF funded program (DRL-1102990), the Cincinnati Engineering Enhanced Math and Science (CEEMS) Partnership, designed to assist teachers in integrating engineering design challenges in traditional math and science courses with required academic standards and high stakes tests that measure student mastery of those standards. Using evaluation and research results from CEEMS, this paper will detail the advantages, as well as the challenges, of integrating engineering design into these courses.

CEEMS targets middle school and high school (grades 6-12) science, technology, engineering, and math (STEM) teachers in 14 regional school districts. Teachers participate in the grant-funded project for two years. They enroll in 20 graduate credits of engineering coursework and participate in professional development at the University of Cincinnati (UC) over two summers and receive support from a "resource team," consisting of experienced educators and engineers who provide guidance during both the summers and two academic years.

With the help of their assigned resource team members, teachers take their summer experiences back to their classrooms by developing units, aligned to content standards that feature engineering design challenges. These units are implemented in the respective teachers' classrooms during the academic year following their summer development.

While many educators laud engineering design as a way to engage students and teach problem solving and valuable 21st century skills, they worry that engineering design challenges will require too much instructional time when they have so many standards to teach prior to testing season. Direct instruction is perceived as a much more efficient way to teach a large amount of material in a short period of time.

However, new evaluation data from CEEMS indicates that engineering design challenges can result in increased mastery of academic content, as compared to traditional instruction. Yet, teaching using design challenges can take more instructional time than didactic approaches, which is a concern for teachers. As a result, teachers need to weigh whether or not the increased mastery is worth the additional time spent. If so, teachers can find creative compromises, such as incorporating several academic standards into one engineering design challenge or reserving challenges for select standards that are difficult for students to grasp without hands-on activities.

This paper will present outcome findings based on pre and post assessment quantitative data comparisons among student participants, as well as findings comparing students of participant teachers and comparison teachers (not trained in engineering design). Qualitative data from participant teachers will provide additional process information. In interviews, teachers outlined the key benefits and drawbacks of using engineering design challenges to teach math and science content. Examining results from all three data sources (student quantitative data, teacher quantitative and qualitative data) may help other teachers determine whether to incorporate engineering design and, if so, which standards are best fits for this type of instruction.

Literature review

Scientific organizations such as the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and the National Science Foundation (NSF) promote student-centered pedagogies such as inquiry, constructivism, and project-based learning as ways to increase student engagement and achievement in science (Anderson, 2012). While K-12 teachers, principals, and administrators express superficial support for these reform efforts, improving student scores on standardized tests often takes precedence in the classroom.

Ever since public policies made standardized test results available to the public, schools experience increasing pressure to do whatever is necessary to raise those scores. When No Child Left Behind was in place, technically speaking, only reading and math scores were truly “high stakes,” as schools and districts whose students did not make Adequate Yearly Progress in those subjects could be subject to negative sanctions. However, science teachers also perceived their students’ publicly available standardized test results to be high stakes, which in turn reinforced a “teach to the test” mentality (Anderson, 2012). In addition, many states have high school graduation tests which include a section on science. While the results of these tests may not be high stakes in terms of sanctions on a school, district or individual teacher, they certainly have

high stakes for the students as their scores determine whether or not they will graduate from high school.

As a result, there is an ongoing tension between STEM-related reforms, often initiated by federal agencies and universities, and test preparation practices K-12 educators perceive will result in higher scores on standardized tests. To further complicate matters, standardized tests consist of largely multiple choice questions and are therefore not necessarily reliable indicators of students' reasoning and problem solving skills (Burkhardt, 2012). Despite researchers' claims that inquiry-based activities aligned with standards-based content can improve students' scores on standardized tests (Anderson, 2012; Blanchard et. al., 2010), most of the 46 principals who were interviewed in one study (Kersiant, Borman, Lee, & Boydston, 2001) expressed concern that teacher participation in an NSF-supported professional development program focusing on constructivist approaches to learning would result in lower student achievement on accountability tests (Anderson, 2012; Kersaint et al., 2001). Findings from observations and interviews with Colorado biology teachers revealed that the pressures of testing reduced the amount of inquiry-based activities in the classroom (Anderson, 2012; Katzmann, 2007). This is not surprising as some teachers report administrators actively dissuading them from teaching anything beyond helping students correctly answer multiple choice questions on standardized tests (Anderson, 2012). Test preparation activities typically consume 20 school days or 10% of the overall learning time for a student (Burkhardt, 2012). In a high poverty school with poor standardized test scores, that percentage may be much higher. It is no surprise that many science teachers are beginning to view science curriculum as fact-based, rather than process-based (Anderson, 2012; Settlage & Meadows, 2002).

However, teachers can also use concerns about improving standardized test scores as an excuse for not trying or adopting more student-centered, constructivist approaches to teaching (Anderson, 2012). The grant-funded project associated with this paper instructs teachers in how to integrate engineering design challenges into the classroom, which can be an intimidating and time-consuming process for many teachers. As many previous grant-funded programs focused on engineering design have demonstrated, effectively changing teachers' instructional practices does not occur overnight, but involves extensive training and support (Brophy, Klein, Portsmouth, & Rogers, 2008). Programs also need to "generate credible research results" that convince the K-12 education community that these reform efforts will move the needle in terms of students' math and science achievement levels (Brophy et al., 2008, p. 384).

Project description

In response to some of the concerns mentioned above, CEEMS has a few unique features. Similar to other programs preceding it, teachers are introduced to engineering disciplines and have the opportunity to practice engineering design activities with other teachers. They are also exposed to engineering and/or STEM curricula and resources that could be used in their classrooms with their students.

However, the program takes teachers one step further and asks them to develop their own engineering design units, uniquely suited for their classrooms, focusing on one or more academic standards they are required to teach. Program support for the teachers' unit development and later implementation of these units comes from several sources. First, teachers take engineering coursework over two summers, in which the pedagogies of engineering design and student-centered challenge-based learning are modeled by instructors. Second, teachers also attend professional development over the same two summers to learn how to integrate some of the same teaching strategies in their own classrooms. Third, a resource team, consisting of experienced, retired or semi-retired engineers and educators, is available both over the summer and during the school year to help teachers both design and implement the units.

In addition to the support provided via the coursework, professional development, and resource team, teachers also received a budget from which they could order supplies for the engineering design challenges planned for their classrooms. While some of the supplies were consumables materials, teachers were also encouraged to use some of the supply budget to purchase equipment which could be used annually in their classrooms if they chose to repeat the engineering design challenges beyond their participation in the project.

Generally speaking, two types of teachers applied to participate in CEEMS. The first type consists of enthusiastic teachers who love to learn and apply new strategies in their classrooms. However, this project also provided generous stipends to the participants, as well as scholarship funds to cover 20 graduate credit hours of coursework, which could be applied to a master's degree in Curriculum & Instruction at UC. As a result, in addition to the enthusiastic teachers, many relatively new teachers also applied to participate with plans to leverage the coursework to earn their master's degree. In fact, approximately 30% of the CEEMS teachers also enrolled in the master's program. As a result, the project included teachers with a wide range of classroom experiences and competencies.

During the teachers' two summers in the program, they develop a total of four engineering design, challenge-based learning units and revise one. Two are implemented in their first academic year in the program. One of those two initial units is revised and implemented again during the second academic year, along with two new units. Thus, five total challenge-based learning units are implemented in two academic years.

As an example of a typical unit, a chemistry teacher sought a creative way to teach the content of intermolecular bonding and stoichiometry. This particular chemistry teacher taught in a rural school where snow days were a frequent occurrence in the winter due to icy roads. He introduced the big idea of safe transportation in icy conditions by showing several YouTube videos of car accidents resulting from snowy or icy roads. Student teams were challenged to design a de-icing product that included a blend of chemical compounds and market it through a commercial. Next, the class brainstormed guiding questions, which covered what chemistry content they needed to learn to design the deicer, as well as questions that clarified the

engineering constraints of the challenge. Some examples of guiding questions for this unit are as follows:

- What is a deicer?
- How do deicers melt ice?
- What chemical compounds are used as deicers?
- What chemicals will we have access to when we design our deicers?
- What environmental risks are associated with the use of deicers?
- What impact will the product have on the surfaces on which it is placed?

The activities leading up to the design challenge consisted of didactic instruction and labs. Students completed three labs prior to working on the challenge. After determining the freezing point of water and the freezing point depression for a solution, the students explored the relationships of the number of particles and molal concentration to the freezing point depression of various solutes. Students then mixed solutes to determine how to lower the freezing point of water. This last lab led directly into the engineering challenge activity where the teams designed a deicer.

Student teams moved through the engineering design process cycle as they sought the best solution to the real world problem—developing an effective deicer. However, the student teams still needed to brainstorm and decide on a product focus. Each team's product was unique. Some teams wanted to design an eco-friendly deicer. Other teams wanted a deicer that was pet friendly, while others teams were more concerned with a product that would melt ice quickly or do minimal damage to roadways. Once a product focus was agreed upon, teams conducted research regarding potential chemical compound blends for their deicer.

Each student team designed three potential products using information gained from their research. Student teams also designed lab procedures, which needed to be approved by the teacher, to test their products' ability to melt ice. Using a rating system developed by the teacher, the teams rated each of their three products in terms of product performance, environmental impact, corrosive effects, and safety. Teams determined which of the three test products to select and refine to represent their final solution.

Teams communicated their final product through a 60 second commercial and brief presentation, which allowed them to utilize their creativity and 21st century skills. From start to finish, the entire process simulated product research, development, and marketing.

During interviews with researchers studying this project, teachers indicate the biggest barrier to implementation was time. Even though the units are created by the teachers themselves, it is time-consuming to incorporate all the elements of challenge-based learning and engineering design. Teachers need to develop a creative “hook” to get students engaged in the challenge's big idea, work with the students to identify an essential question for the unit, allow students the opportunity to suggest ideas for the engineering design challenge, and then facilitate

the process of students generating guiding questions for the challenge. Next, after teaching the necessary academic standards aligned to the unit, the students work in teams to develop solutions for the challenge using the engineering design process. The engineering design process is iterative in nature. Thus, for every solution developed, students must test that solution and make refinements in order to improve and optimize the solution. Most units end with team presentations of proposed design solutions. While all of these steps can contribute to student mastery of content and acquisition of 21st century skills, they do consume a lot of class time.

Beyond the time commitment related to CEEMS program requirements, interview data reveals other school-related time pressures teachers believe sap valuable instructional time, including time devoted to testing and test preparation, school assemblies, pep rallies, and snow days. In urban schools, student attendance issues further complicate matters. Other school-imposed policies make teachers reluctant to try new pedagogies, especially if they take more time. Curriculum pacing guides require teachers to stay on schedule in terms of when particular topics are taught. If teachers are behind schedule due to incorporating engineering design challenge activities, they may be perceived negatively by the school principal, especially if it appears that all necessary content standards will not be covered prior to testing season. Also, teachers in schools with shorter bell schedules (less than 45 minutes long) are at a disadvantage when incorporating hands-on projects. It takes time to distribute materials at the beginning of each class and then clean up materials at the end of the bell. Longer bell schedules or block schedules are generally preferable for project-based work.

For some teachers, the barrier of time seems insurmountable. Others embrace this new way of teaching, even after their time in the program comes to an end and they are no longer required to teach using challenge-based learning and engineering design. What makes the difference?

Two factors emerge as teachers weigh the cost-benefit analysis to this new way of teaching. First, the selection of academic standard(s) to be addressed by the units, as well as determining how those standards are incorporated into the units' engineering challenges seems to be a key to success. Second, to buy-in, teachers need to see a concrete benefit for their students. Increased student engagement and reduced classroom management issues help, but witnessing students' increased mastery of standards is a far better motivation.

Careful selection of standards

The teachers are encouraged to make intentional choices regarding the academic standards selected for each engineering design unit. Since the teachers are creators of these instructional materials, they have more "buy-in" when required to implement the units, as the activities and standards are uniquely suited to their students and the academic standards to which they are accountable.

While a few teachers may develop engineering design challenge units solely on the basis of their own personal interests or what they think the students might enjoy, teachers are highly

encouraged to carefully consider the standards selected for each unit and ensure that the engineering challenge itself will require students to apply math and/or science content to develop a solution. Not all content lends itself to this type of teaching. Some content may be better delivered using more traditional pedagogies.

A few factors may justify the use of an engineering design challenge and increased time spent on the topic. For example, some concepts in science or math are difficult for students to grasp and the use of a hands-on project, such as a design challenge, helps facilitate that understanding. Some teachers analyze standardized data from their past students and realize they have historically performed poorly on sections emphasizing certain standards. As a result, an increased focus on those specific standards may be in order, which could include the use of an engineering design challenge. Similarly, some standards are heavily represented on high stakes or standardized tests and therefore it makes sense to spend more instructional time devoted to teaching those standards. Finally, design challenges can be a way to bundle several key standards in one unit and show that content is inter-related in the real world.

Hands on projects, such as engineering design challenges, can help students grasp difficult academic concepts. For example, an AP calculus teacher described how using a real-world application helped her students better understand related rates (The College Board, 2015). Students created a rain barrel and delivery system to effectively supply water to plants. Students used their knowledge of related rates to test the rate of water flowing out and calculate the rate of water volume changes. The teacher explains why she intentionally selected related rates, a key concept on the AP Calculus AB exam, as the topic for a unit featuring an engineering design challenge:

I selected this unit because historically, related rates is a topic that is hard for students to grasp during the first round of teaching. Typically, it takes until the review before the AP exam for students to understand it. This is a topic where real world applications are said to occur, but often hard to see. The purpose of this unit was met because students were able to see how related rates was used in water flow and ultimately in the design of a rain barrel.

A math teacher echoes similar sentiments about the utility of subject application regarding trigonometry:

Students, when presented with trigonometry, are often confused and sometimes turned off by the subject. If sound is studied (using a free program such as Audacity) by looking at its wave format, using somewhat familiar terms such as amplitude and frequency, students may become more appreciative of sine and cosine functions.

Thus, the teacher taught these concepts by challenging student teams to design and build musical instruments that could be tuned to play a simple song. As an added bonus, this unit was introduced in a performing arts school, which resulted in increased engagement in the challenge.

Science teachers also discuss how some academic topics are best taught using hands-on pedagogies. For instance, density is a difficult topic for students to understand conceptually according to some science teachers. Hands-on activities, including engineering design challenges, can help facilitate understanding of density. For examples, a middle school teacher created an engineering design unit specifically related to density. Students created “submarines” using two liter bottles and creatively problem solved ways to get their submarines to complete various performance tasks in a fish tank. The submarines needed to sink to the bottom of a fish tank filled with water, retrieve an object, and then rise to top of the tank. Students could not physically touch the submarine once it was in the water, so they needed to creatively design and re-design the submarines to perform the needed tasks based on their knowledge of density.

Similarly, a high physical science school teacher used the challenge of designing a tabletop hovercraft to help her students understand friction:

Accomplishing the challenge of designing a hovercraft will allow students to investigate the frictional force in an authentic way. Students carry many misconceptions about how things interact and move, and this (unit) will provide authentic opportunities to correct these (misconceptions).

However, in her reflection on the unit, she did note that “the length of time needed for the design project required significantly more time (over two weeks due to snow days) than is typically needed to cover the topic of friction: 2-3 days.” Teachers continually need to assess whether additional time spent on a topic, even if student understanding increases, is worth the investment.

Another middle school science teacher taught her students the properties of rocks, minerals, and soils by having them design eco-friendly paint by grinding rocks and minerals into pigment and combining them with a binder. She noted, “I chose this unit because students struggle to remember the properties of rocks, minerals, and soils.” Using this new teaching method, the average pre-assessment score of 15% (percentage of correct responses) jumped to an average of 77.5% on the post-assessment, which the teacher perceived to be a remarkable improvement as compared to student mastery of this topic in previous years.

Other teachers chose units based on previous classes’ performance on assessments. An AP chemistry teacher observed that each year, her students would struggle with the thermochemistry content, specifically heat and calorimetry. As a result, the majority of her students would need to complete test remediation because their test scores were below a passing score of 70%. Thus, she adapted a calorimetry lab activity to a hand warmer engineering design challenge and saw the number of students needing test remediation drastically reduce to just 12 of 53 students with an average score of 73% on the final test. She used similar reasoning when creating a design challenge tied to the testing and identification of the types of solids. Students were called to a fictional crime scene and asked to identify the types of substances present. In the prior year, when using traditional, didactic teaching methods, the average test score was 68%. When she

taught the content in the context of a design challenge, the average test score rose to 75%. While the test score differences could be attributed to the varying student abilities from one year to the next, the improved scores nevertheless bolstered the teacher's confidence in the new teaching pedagogies.

Standardized test results from previous years also drive teachers' decision-making regarding the selection of content for engineering design units. Based on the previous year's results from the state mandated achievement results, a seventh grade math teacher noted only 41% of her students were above proficient in the category involving integers, fractions, decimals, percents, exponents, square roots, absolute value, and scientific notation, as opposed to 47% of the students in her district overall. As a result, she determined those concepts required more focus in her classroom and created a relevant unit, Using Percents to Reduce Your Carbon Footprint, where students needed to learn the percent equation and make percent calculations, including percent increase and decrease, based on their families' usage of nonrenewable resources and propose a plan to reduce their respective families' carbon footprint. Likewise, a middle school math teacher noted her students struggled with the physical science portion of the state-mandated science test and thus felt justified in developing and implementing a lengthy engineering design unit covering key multiple physical science standards, Waves, Circuits, and Roller Coasters.

A high school math teacher co-taught classes with an intervention specialist, as most of his students were on individualized education plans (IEPs) and almost all struggled in math. These students need to pass all four parts of the state graduation test in order to graduate from high school. Questions about right angle trigonometry were always present on the graduation test and thus served as a topic of concern for many students in this teacher's class. Thus, he created an engineering design challenge where students incorporated right angle trigonometry to design a platform capable of holding the most weight. He reasoned, "Eighty percent of my students will move on to a vocational school setting. Creating a lesson where they can use their hands allows them to better understand this type of mathematics."

Finally, some program teachers approach the engineering design units as an opportunity to bundle a number of skills and standards into one unit. After all, in the real world, engineers apply multiple concepts from a variety of disciplines in order to solve a problem. For example, one CEEMS teacher taught math to eighth graders. His assigned course, Integrated Math, covers both eighth grade math standards, as well as high school algebra content, which is a lot of content to cover in one year's time. In order to cover this much content and fulfill program requirements, he knew he needed to cover multiple content standards in his units. For example, his Barbie Bungee unit utilized eighth grade standards of statistics and probability in addition to linear functions. Another algebra teacher taught a unit in which students created a product out of simple materials to use solar energy to heat water. She integrated multiple math standards throughout the challenge, including rate of change, linear functions, slope, scatter plots, and creating equations. As a result, she commented in her unit reflection, "We were able to practice

several skills within this unit, so it never felt like time was lost. My students showed growth in this content that I haven't always seen in the past.”

Cautions related to the creation of engineering design challenges

Conversely, the CEEMS project team and resource team discourage teachers from developing units related to standards underemphasized on state standards or standardized tests. While all standards need to be taught, it is not prudent to design a two to three week engineering design unit highlighting standards that are not foundational or will only be addressed in a few isolated questions on standardized tests. For example, a high school geometry teacher developed an engineering challenge focused on surface area and volume, as those are usually key standards enhanced by hands-on activities. However, after the unit was created over the summer, her department head attended professional development on the upcoming state graduation test and shared with the rest of the math teachers that surface area and volume would be barely covered on the test that academic year. As a result, the teacher moved her surface area and volume unit to the end of the year, after state testing, so she can focus on academic standards that will dominate the test prior to it being administered.

In addition, teachers are cautioned against designing engineering challenges that students can solve using trial and error without needing to apply science and math principles. For instance, a middle school math teacher designed a unit in which her students designed and built rubber band powered rovers and then asked them to apply the distance formula to determine how far their rovers travelled. While this was an engaging activity and the real world use of the distance formula was likely helpful for the students, the designing and building of the rovers had no relevance to the math content. However, if the design of the rovers had been combined with a science class learning about elastic potential energy, this could have been a rich inter-disciplinary unit.

Similarly, a middle school science teacher created a unit focused on the content of the hydrologic cycle and the impact of pollution on the physical environment. The unit included a field trip to a highly polluted local creek where students tested the water quality and, as a community service activity, cleaned up litter around the creek area. The design challenge for this unit involved the students using recycled materials to design a new, useful product for society. Again, though students likely benefitted from learning that materials can be recycled for new uses, this design activity had no relevance to the hydrologic cycle or any other state standards. A more relevant challenge may have involved having students design a model or filter to purify water for human consumption.

The CEEMS project team and resource team members observed teacher developed units improve as the program matured. Although part of this improvement could be attributed to better teacher selection, the project team and resource team themselves also became more adept

at advising teachers regarding standards selection and the identification of potential challenge activities as they learned from the successes and mistakes of the earlier cohorts.

Perceived benefit to students

Teachers develop a pre- and post-assessment for each CEEMS unit focused on the respective academic content standards tied to that particular unit. The assessments are short answer in nature, similar to standardized tests. Teachers analyze the differences between the pre and post-assessment scores prior to sending the data, minus student names, to the project's external evaluator. Since the beginning of the project, over 95% of units implemented resulted in statistically significant gains from pre to post-assessment.

To some degree, this increase is expected, as one would assume that students' content knowledge would improve after receiving instruction, regardless of the pedagogical approach utilized. However, in the 2015-2016 school year, the CEEMS external evaluation team identified comparison teachers for the majority of CEEMS participants. In order to serve as a comparison teacher, teachers needed to teach in the same building, district, or a district with similar student demographics and teach the same course and/or academic standards as the CEEMS teacher. Both the comparison teacher and the CEEMS teacher would give their students the same pre and post-assessments (see **Appendix** for example) prior to and immediately after teaching the academic standards covered in the assessment. One of the short-comings of this evaluation measure is that, in most cases, the program teacher was the one who designed or selected the assessment; it would have been preferable if the CEEMS and comparison teachers could have collaborated on the assessment. Nevertheless, the program teacher was instructed to limit the assessment to an understanding of the standards covered and use districtwide or schoolwide short-term assessments if available. The **Appendix** includes an example of a pre and post-assessment for an eighth grade science unit entitled Science Says Safer Sports. This particular assessment was chosen by the CEEMS teacher because the first half was designed collaboratively and administered each year by all the school's eighth grade science teachers. The CEEMS teacher developed the questions for the second half of the assessment herself. The unit addresses the standards of forces and motion through the context of discussing the issue of concussions and safety factors related to the design of a helmet. However, the pre and post-assessment addresses only content related to forces and motion; no questions relate to concussions or even use concussions or sports-related injuries as examples in questions related to forces.

CEEMS teachers' students ($n=1,458$) showed a higher mean difference in knowledge gain of 8.5% on the post-test than comparison teachers' students ($n=1,070$). The difference was statistically significant ($F_{(1,2546)}=87.65$, $p<0.001$) (Morrison, Maltbie, Friedman, & Dariotis, 2016). In most cases, CEEMS teachers were aware of their students' gains, as compared to the gains of the comparison class or classes. This awareness helped bolster their confidence in the

new teaching pedagogies as they could see the possible contribution the new pedagogies made in their students' understanding of academic content.

Teachers and students also self-reported that using engineering design challenges increased student understanding of academic content. In post-unit surveys, “82.8% of students agreed or strongly agreed that using challenges was a ‘more effective way to learn’ than how they are usually taught” and 79.5% of teachers agreed or strongly agreed that “their students mastered the unit content” (Morrison et al., 2016, p. 6).

Additionally, in the 2015-2016 external evaluation of the program, 96.1% of teachers agreed or strongly agreed that “student engagement increased during engineering design units, as opposed to non-engineering design units” (Morrison et al., 2016, p. 4). Many commented engagement increased even among students typically disengaged in school work:

I found that students who ordinarily were not engaged actively participated and those who were forcing themselves to do the routine work actually enjoyed this way of learning. They realized that engineering is not just guessing, but requires using science and technology. This is the answer to the age old question so many students ask: “Why do I need to learn this? I'll never use it.” (Morrison et al., 2016, p. 5)

Conclusions

Despite the increase in instructional time required to implement an engineering design unit with fidelity, some teacher participants are internalizing this pedagogy and using it outside of their “CEEMS required” units as they see for themselves the benefits for students in terms of content knowledge gains and engagement. A few CEEMS participants report planning additional engineering design units to cover their entire course curriculum, which is above and beyond expectations. Other participants borrow units from their fellow participants and implement those in addition to the two to three units per year they are required to teach as part of the program.

However, some standards seem to be better suited for this type of teaching than others. It may be unrealistic to expect teachers to adopt these strategies for every unit as the time involved in executing an authentic, meaningful engineering design challenge can be significant. On average, engineering design challenges developed and implemented thus far as part of this project took at least two weeks to complete. A healthy balance of teaching strategies may be necessary in order to cover the content required in an academic year while still challenging students to utilize higher level thinking skills associated with this pedagogy. Challenge-based learning and similar pedagogies, such as problem-based and project-based learning, are very engaging and help students transfer knowledge to solve real world problems. On the other hand, math and science teachers have many standards to cover over the course of a school year. Thus,

it may be more prudent and time efficient for teachers to utilize challenge-based learning a few times each year to teach intentionally selected standards. As one teacher articulated in a post-unit survey, “The time constraint with CBL [challenge based learning] is the only reason I do not use it on a daily basis.” In the interest of time, more traditional strategies can be used to teach other topics. In CEEMS, teachers would regularly discuss this healthy balance with other teachers in the program and their resource team coaches. Similarly, teachers not participating in a formal program, such as CEEMS, could be encouraged to seek out a community of practice of like-minded peers, with whom they can honestly discuss when to use engineering design challenges and when to teach content using traditional pedagogies.

In addition to the careful selection of standards, other factors not addressed in this paper may help mitigate the barrier of time. Block scheduling can be a better fit for engineering design challenges, as it permits student teams to work for a longer, more concentrated period of time on their designs. Teaming in middle schools allows teachers in different disciplines to develop inter-disciplinary engineering design units. The science teacher can teach the science involved in the unit, the math teacher can teach the math portion, and the English/Language Arts teacher can guide the development of the final report or presentation. Anecdotally, some middle school teachers involved in CEEMS taught inter-disciplinary units with teachers of other disciplines on their teaching teams and reported great success. In addition, two high schools in the program incorporated intersessions (weeks between academic quarters) into their school calendars. Students spent intersessions engaged in project-based learning experiences, many of which incorporated engineering design challenges. Overall, school personnel need to avoid an “all or nothing” approach in regards to incorporating engineering design challenges and embrace creative compromises which empower students to act as engineers at least a few times a year.

Next Steps

CEEMS was funded by a research grant, which provided participating teachers with generous stipends, scholarships to cover 20 graduate credit hours, resource team coaches, and a supplies budget. After the grant funding ends, how does the project team continue to sustain and scale its efforts? Part of the answer relates to institutionalizing the coursework developed as a result of the grant. A sub-set of these courses has already been approved by the university as a distance learning graduate certificate program with the CEEMS teachers being the first graduates. The capstone course developed as the final course in the certificate program mimics the coaching process embedded in the program. Teachers develop a unit featuring an engineering design process with the help of a virtual coach, implement the unit in their actual classroom, and then reflect on and refine the unit with the coach’s assistance. The graduate certificate program is aligned with a master’s degree in Curriculum and Instruction. As a result, the graduate certificate courses can count towards both the certificate and a master’s degree if desired. For teachers who do not wish to take graduate coursework, the experience of designing a unit with a

coach's help, implementing the unit, and reflecting on its implementation has been packaged into a professional development opportunity where the teacher and coach interact virtually over a three month period. As a result, there are other avenues available for teachers to learn and practice these instructional strategies without participating in a two year program.

In addition, while CEEMS evaluation results so far are promising, more research is needed to demonstrate whether engineering design challenge activities truly result in a positive impact on students' acquisition of critical math and science content. Even more convincing would be data tied to standardized test results, as those results drive school and district decision making regarding pedagogy and content. In consultation with its advisory board in the early years of the project, the CEEMS project team purposefully decided not to measure their success based on standardized test scores. Since teachers were only required to teach 2-3 units as year using the program pedagogies, the project team believed standardized test results would not be an accurate measure and chose instead to examine content knowledge acquisition relative to those specific units, which resulted in the creation of the individualized pre and post assessments referenced above. While these targeted assessments likely paint a more accurate picture of the program's impact, they may lack the persuasive power of altered standardized test scores within the K-12 community.

As a larger societal issue, part of the issue might be the nature of the standardized tests themselves. Burkhardt argues for "tests worth teaching to" that include performance tasks, as opposed to tests almost exclusively composed of multiple choice and short answer items (Burkhardt, 2012). Although multiple choice and short answer tests are easier and less expensive to score, they often fail to measure whether students can apply science, engineering, and mathematical practices. The K-12 community may continue to offer lip service to the importance of high level thinking, reasoning, and 21st century skills, but teaching practices will likely stay the same if the state accountability tests are only measuring basic recall of facts and comprehension skills.

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APPENDIX:

Sample Pre and Post Assessment from Science Says Safer Sports

Lesson Title: Protecting fragile objects in sports	Unit #: 3	Lesson #: 1	Activity #: 1	Worksheet: a
Activity Title: Force and Motion Basics				
Worksheet Title: Pre-Test				

Part 1: CER

There are many forces acting on this car. Two of them are shown. What is the net (resulting) force?



- Which claim is correct? The net force is...
 - 30 N to the right
 - 30 N to the left
 - 70 N to the right
 - 70 N to the left
- What evidence from the data supports your claim?
 - Subtracting forces equals 30 N and the larger force is pushing left.
 - Subtracting forces equals 30 N and the larger force is pushing right.
 - Adding forces equals 70 N and the larger force is pushing left.
 - Adding forces equals 70 N and the larger force is pushing right.
- What scientific reasoning supports your evidence?
 - Forces that are in the same direction must be added and move in same directions as the stronger force.
 - Forces that are opposite and equal must be subtracted and there is no change in motion.
 - Forces that are opposite and unequal must be added and movement is in the same direction as the stronger force.
 - Forces that are opposite and unequal must be subtracted and movement is in the same direction as the stronger force.

Part 2: Literacy

Read the article and answer the questions.

The Physics of Baseball (Source: <https://student.societyforscience.org/search?tag=Energy>)

On June 12, the Kansas City Royals played at home against the Detroit Tigers. When Royals centerfielder Lorenzo Cain stepped up to the plate at the bottom of the ninth, things looked grim. The Royals hadn't scored a single run. The Tigers had two. If Cain struck out, the game would be over. No player wants to lose — especially at home.

Cain got off to a rocky start with two strikes. On the mound, Tigers pitcher Jose Valverde wound up. He let fly a special fastball: The pitch whizzed toward Cain at more than 90 miles (145 kilometers) per hour. Cain watched, swung and CRACK! The ball flew up, up, up and away. In the stands at Kauffman Stadium, 24,564 fans watched anxiously, their hopes rising with the ball as it climbed through the air.

The cheering fans weren't the only ones watching. Radar or cameras track the path of virtually every baseball in major league stadiums. Computer programs can use those tools to generate data about the ball's position and speed. Scientists also keep a close eye on the ball and study it with all those data.

Some do it because they love baseball. Other researchers may be more fascinated by the science behind the game. They study how all of its fast-moving parts fit together. Physics is the science of studying energy and objects in motion. And with plenty of fast-swinging bats and flying balls, baseball is a constant display of physics in action.

Scientists feed game-related data into specialized computer programs — like the one called PITCH f/x, which analyzes pitches — to determine the speed, spin and path taken by the ball during each pitch. They can compare Valverde's special pitch to those thrown by other pitchers — or even by Valverde himself, in previous games. The experts also can analyze Cain's swing to see what he did to make the ball sail so high and far.

When Cain swung his bat that night, he connected with Valverde's pitch. He successfully transferred energy from his body to his bat. And from the bat to the ball. Fans may have understood those connections. More importantly, they saw that Cain had given the Royals a chance to win the game.

4. What tool do physicists use to collect evidence on the speed of pitches?
 - a. Spin
 - b. Radar
 - c. Energy
 - d. Royals
5. How can baseball players use the data collected from this study on pitches?
 - a. To better understand the speed and location of pitches.
 - b. To decide how many innings should be in game.
 - c. To predict game winners.

- d. To improve nutrition.

13. A bowling ball has a mass of approximately 5000g. If I drop it from the school roof, what will be the amount of force applied to the ball? Assume the rate of acceleration is 9.8 m/s. Show your work.

14. A baseball has a mass of approximately 145g. If I drop it from the school roof, what will be the amount of force applied to the ball? Assume the rate of acceleration is 9.8 m/s. Show your work.