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Shaking Up Pre-Calculus: Incorporating Engineering into K-12 Curricula

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ABSTRACT

Projects highlighting **S**cience, **T**echnology, **E**ngineering, and **M**athematics (STEM) education in high schools have promoted student interest in engineering-related fields and enhanced student understanding of mathematics and science concepts. The Science and Technology Enhancement Program (Project STEP), funded by a NSF GK-12 grant at the University of Cincinnati, is one community partnership that focused on improving STEM skills and communication. As a product of Project STEP, a lesson was developed and implemented in a local Cincinnati high school classroom on applying Trigonometry functions in pre-calculus to the study of Earthquake Engineering vibrations. This lesson, Shaking Up Pre-Calculus, shows that student involvement, understanding of the material, and interest in engineering can all be enhanced through innovative educational practices. Moreover, inquiry based lessons of this type can easily be made to meet educational standards and be incorporated into existing curricula. An overview, objectives, standards addressed, and assessments of the lesson are presented here in detail. Additionally, assessment results, student feedback, and reflections from the program participants are offered.

Key Words: Project-Based Learning; Active Learning, Earthquake Engineering, Pre-Calculus

INTRODUCTION

Education Week reported, ". . . science classes are more likely than math . . . to have a heavy emphasis on increasing students' interest in the subject. However in both subjects, that objective is less emphasized in high school than at earlier grades" (Robelen, 2013, para. 14). Therefore, a study of high school STEM interest is timely. As part of a National Science Foundation Graduate STEM Fellows in K-12 Education Program (NSF GK-12) grant, entitled Science and Technology Enhancement Program (Project STEP), graduate engineering students at the University of Cincinnati merged into high school classrooms for at least 10 hours a week for a full academic year (Project STEP, 2010). The graduate engineering students created and implemented high school lessons trying to increase high school student interest in STEM.

This grant was an example of successful partnerships between high school teachers, high school students, university students, and university faculty members. The GK-12 grant was set up to enhance graduate engineering student communication of technical knowledge to a non-technical audience and to encourage collaboration between future faculty members and K-12 institutions. However, strong STEM lessons for use by middle and high school STEM teachers were a product of these partnerships. While Project STEP finished its 11th and final year at the University of Cincinnati in 2012, all of the STEM lessons that were created over the course of the program are available to the public for free on the website (http://www.eng.uc.edu/step).

This article describes and discusses the impact of one high school lesson, called *Shaking Up Pre-Calculus*, created by Chelsea Sabo, influenced by Lois Childers, modified by Andrea Burrows, and critiqued by Richard Miller. As a part of Project STEP, the high school teacher, Lois Childers, and the then graduate engineering student, Chelsea Sabo, worked together to create, implement, and evaluate lessons that brought engineering content to the all female student body at Seton High School in Cincinnati, OH. Ultimately, these Project STEP lessons provide a good example for future development of high school lesson plans which promote STEM and are "complete" in that any teacher can find the lesson online and have all the details necessary to implement the lesson in his/her own classroom.

LITERATURE SURVEY

Wernher Von Braun said, "Research is what I'm doing when I don't know what I'm doing." Too often in classrooms teachers expect students to know what they are doing at all times. In order to have successful STEM classrooms, there need to be this sense of fostered exploration that engineering research can provide (Fuller, 2001). Additionally, there is a need for students to pursue STEM fields in order to fill the career openings of the future (Bieber, Marchese, & Engelberg, 2005; Chen, 2009). For Americans to stay competitive in the world market, STEM education must be highlighted. Emphasizing the technology, there is a "rapidly emerging awareness in America that technology is not just a ubiquitous component of contemporary culture, but also one of the critical keys to global competitiveness" (Sanders, 2009, p. 25). In order to meet this challenge, STEM teachers must embrace new ways of approaching old material such as learning from engineers and the research community.

Engineering in K-12 Education opens by explaining:

> *The presence of engineering in K-12 classrooms is an important phenomenon, not because of the number of students impacted, which is still small relative to other school subjects, but because of the implications of engineering education for the future of science, technology, engineering, and math (STEM) education more broadly. Specifically, as elaborated in the full report, K-12 engineering education may improve student learning and achievement in science and math; increase awareness of engineering and the work of engineers; boost youth interest in pursuing engineering as a career; and increase the technological literacy of all students" (Katehi, Pearson, & Feder, 2009, p. 1).*

Students need to be prepared *in* STEM *for* STEM careers. Chen (2009) found that "strong academic preparation in high school was associated with a higher STEM degree completion rate" (p. 17). Others have found that the quality of science and mathematics teaching at the high school level plays an important role in students choosing engineering majors/careers at the university level (de Lucena, de Lucena, Magalhaes do Valle, Claro, & da Fonseca de Lira, 2011). To achieve goals such as strong academic preparation and quality in STEM teaching, STEM proponents encourage the use of inquiry projects, problem based learning projects, and active learning. Understanding these terms aids in placing *Shaking Up Pre-Calculus* among other lessons.

First according to Martin-Hansen (2002), types of inquiry projects include open/full inquiry, guided inquiry, coupled inquiry, or structured inquiry. Open inquiry relies on a student-centered approach where students create questions, design experiments, conduct investigations, and communicate results. Guided inquiry allows the teacher to pose a question for investigation and then letting students decide how to continue through the experiment and create conclusions. Coupled inquiry involves a teacher's question followed by students creating their own follow-up questions and procedures for the experiment and finally settling on a resolution with an assessment. Structured inquiry is mainly directed by the teacher, and is the more traditionally used model. Any of these approaches would be suitable for hands-on lessons. Secondly, the Buck Institute for Education proposed project based learning in the 1990's. Some studies even show that students' conceptual gains with inquiry-based activities averaged more than twice the gains found without inquiry activities (Prince, Vigeant, & Nottis, 2006, ASEE).

Outstanding project-based learning focuses on projects that include: 1) Student capability put at the center of the learning process, 2) Work that is central rather than peripheral to the curriculum, 3) Provocative issues or questions that lead students to in-depth exploration of authentic topics, 4) Essential tools and skills – like technology – for learning, 5) Products that solve problems, explain dilemmas, or present information generated through research, 6) Multiple products that permit frequent feedback, 7) Performance-based assessments that communicate high expectations, rigorous challenges, and 8) Collaboration in some form (Markham, Larmer, Ravitz, 2003). “Research suggests that [project-based learning] . . . appear[s] to improve retention, student satisfaction, diversity, and student learning” (Dym et al., 2005, p. 114). Recommendations for designing project-based learning environments from Dym et al. include: 1) Using classes as laboratories where research is conducted, 2) Obtaining both quantitative and qualitative data, 3) Embracing global networks, 4) Engaging design coaches to maintain the context of engineering, 5) Challenging instructors to incorporate design into all parts of curriculum, 6) Defining possible gains by using design strategies up front, and 7) Providing more practice for beginners and experts to collaborate.

Finally, active learning highlights student actions such as reading, writing, discussing, problem solving, and similar classroom engagements as project-based learning. Examples of active learning can include students sharing ideas with peers, studying in groups, or reacting to debates with others. Active learning is vital because of the impact that the strategies have on student learning (Bonwell & Eison, 1991). In addition to students preferring active learning strategies such as image analysis and open-ended questions, they have been shown to improve student retention, promote deeper understanding of material, and increase logical thinking skills (McConnell et al., 2003).

STEM engagement is an ever-increasing area of interest by which students can be immersed through many different means. Examples of STEM activities occur in after school programs (Bieber et al., 2005; Miller & Ward, Sienkiewicz, & Antonuicci, 2010), in innovative programs such as integrated teaching and learning (Carlson & Sullivan, 1999), and active learning strategies for the classroom (McConnell, Steer, & Owens, 2003). Whether outside of the school day or during it, lessons taught through engineering design, which include inquiry, project-based learning, and active learning, can enhance and promote STEM. “Engineering is an integrative process and thus engineering education . . . should be designed toward that end” (Bordogna, Fromm, & Ernst, 1993, p 3). Suggestions from Bordogna et al. include: 1) Focusing on the broad educational experience where individual concepts are connected and integrated, and 2) Viewing students as professionals to make engineering more attractive, exciting, and fulfilling so they connect with the materials. To more adequately prepare students to engage in engineering, there is a trend towards increasing the engineering design component in curricula (Dutson, Todd, Magleby, & Sorensen, 1997). However, "design thinking is complex" (Dym, Agogino, Ozgur, Frey, & Leifer, 2005, p. 103).

Although teaching students to think like engineers is complex, there is hope for the all students of today and tomorrow. K-12 teachers can increase the numbers of students interested in STEM and improve comprehension simultaneously (Burrows, Borowczak, Slater, & Haynes, 2012). One way to tap into rich STEM content is to encourage the teachers to value their existing partnerships. Teachers often have diverse backgrounds, access to emerging research in the field, or the ability to connect with professionals; which allows them to bring STEM, and thus engineering design, into their classes. While there are many examples of successful interventions of curricula content and outreach activities in the last 10 years in P-12 engineering education (Mendoza & Cox, 2012), teachers need to ". . . above all, recognize that more effort needs to be expended on strategies to promote the adoption and implementation of STEM reforms . . ." (Fairweather, 2008, p. 28). In addition to the suggestions for lesson implementation above, work still needs to be done to address standards if these lessons are to be used in practice (Mendoza & Cox, 2012).

Thus, like VonBraun believed, William Lawrence Bragg reiterated, "The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them."

NSF GK-12 PROJECT STEP LESSONS

Operating within the NSF Division of Graduate Education, GK-12 was designed to improve STEM graduate students' communication, teaching, collaboration, and teamwork skills; provide professional development opportunities to K-12 teachers; enrich the learning of K-12 students; and foster stronger partnerships between institutions of higher education and local school districts. In 1999, NSF launched the GK-12 Program, which provided financial and educational support to graduate students in STEM to work with teachers and their students in K-12 settings. It also provided grants to Institutions of Higher Education (IHEs) to fund STEM graduate students through GK-12 Fellowships.

Project STEP was one of the projects funded by an NSF GK-12 grant in 2001. Although operated and managed at the university level, Project STEP was a true community partnership (Burrows, 2011) which supported the interaction between graduate engineering students as Fellows, high schools, high school teachers, high school students, and university faculty. Directly in contact with these teachers and students for 10 hours each week were the graduate engineering students. The graduate students also worked in conjunction with their research advisors while involved with Project STEP (Project STEP, 2010).

Project STEP focused on the graduate engineering students in different engineering fields. Accordingly, goal one of Project STEP was a need for improved communication of STEM subjects by the graduate students, or in other words the future faculty of STEM disciplines. With these graduate students interacting with high school students and teachers on a weekly basis, their ability to explain their research became more succinct, efficient, and knowledge level appropriate. Additionally, the grant contained goals concerning high school student learning and sustainability of the Project STEP program.

Evidence of graduate engineering student improvements was gathered via weekly self reports, lesson plans, interaction with engineering and education faculty, and the successful completion of four courses. The graduate students participated in a summer training course, called Instructional Planning, which prepared the graduate students for their upcoming work with high school students and teachers. The course involved training of high school culture, lesson planning, and meta-cognitive activities regarding the graduate student experiences. The graduate students then continued their training during the academic year with practicum classes.

The graduate engineering students were required to create five high school lessons during the academic year. These lessons contained measurable objectives, a STEM focus, an engineering connection, a hands-on activity, both a pre and post assessment, and an ending review. The graduate students were free to create lessons that reflected both their personality and their expertise in STEM content.

An ultimate goal of these lessons was for students to gain a deeper and lasting understanding of the STEM concepts presented. This was done by integrating lessons learned from inquiry projects, project-based learning, and active learning literature. The requirement for hands-on activities was aimed to get students actively involved in their learning which has shown an increase in student satisfaction and learning (Dym et al., 2005). Also in these lessons, real world applications, career connections, and the societal impacts of the engineering concept were explored. Not only can introducing the engineering design processes into a lesson make it easier to tie in suggestions from inquiry projects, problem based learning, and active learning, but by doing so, teachers can ultimately increase student interest in STEM fields.

While not all lessons developed from Project STEP met all of these goals, *Shaking Up Pre-Calculus* was an adroit example of how to accomplish many of them. Due to the practicality of implementing and integrating these lessons in high school classrooms, limited reporting was obtained in the form of pre- and post- assessments and student feedback forms. However with this information and the feedback of those involved, a sense of the impact of these lessons can be gained. The authors of this paper believe that lesson plans developed around engineering design can promote more interest in STEM, improve understanding, increase student involvement, and still fit within the framework of current curricula.

SHAKING UP PRE-CALCULUS LESSON

As part of Project STEP, a lesson plan was created and implemented to connect applications of Trigonometry with vibration analysis of structures in engineering. The main focus of the lesson was on Earthquake Engineering, which is the study of the behavior of structures under seismic loading. This involved studying the natural response of structures when excitation was introduced and designing, implementing, and analyzing ways to reduce the vibrations in buildings. As detailed in this lesson on the website, these concepts tie in directly with those studied in trigonometry. That is, wave amplitude and frequency, exponential decay, and response over time.

Shaking Up Pre-Calculus is the revised and reorganized version (used in the 2nd year) after incorporating lessons learned from the first year. The lesson was altered to make enhanced connections to current learning objectives of the course and incorporate more accountability. This included an additional homework assignment after day two for the students to practice the material and a final quiz. Additionally, it is organized more efficiently to utilize time and also omits a pre-lesson activity focused on sound waves as it does not directly tie in with the concepts of vibration analysis in engineering (it was used a precursor to the lesson to review concepts of amplitude and frequency).

In addition to the lesson details, the standards met by this lesson, applications, career connections, and societal impact are presented. This not only helps the educator achieve and meet the necessary benchmarks of a high school education, but also to put in context the learning material for the students.

Lesson Overview

Table 1 shows an overview of the timeline, objectives, daily activities, and assessments associated with *Shaking Up Pre-Calculus*. Additionally, students were given a pre- and post- assessment prior to the start, and immediately after, the completion of the lesson (detailed in a later section). This was not graded but used as an indicator of student learning and as a guide for teacher improvement. Full details of the lesson are available at http://www.eng.uc.edu/step/lessons_pages/shake_up_precalc/shake_up_precalc.html.

In this lesson, students learned about the fundamentals of vibrations and how the concept applies to sine and cosine functions. This was done by having the students build houses with KNEX and completing testing on a homemade "miniature" shake table. While the shake table was used to introduce vibrations similar to those seen during an earthquake (or during real-life experimental testing), data was only collected once the table was turned off so that the natural dissipation could be analyzed. Using data taken from motion sensors, the students found an equation for the

	Objectives	Activity	Assessment
Day 1	• List the general form for a sine and cosine wave. • Draw the graph of a sine and cosine function.	• Show a video of a structure being shaken by an earthquake or simulated earthquake, giving an overview of the lesson and the objective. • In teams, students build a structure to be tested on the shake table.	
Day 2	• Identify the natural frequency and damping coefficient when given an equation.	• Demonstrate the shake table with a sample house. • Show how to find the equation of a damped sinusoid.	**Homework Assignment** Worksheet – Finding the Equation from Given Graphs of Damped Sinusoids
Day 3	• Model collected data with a damped sinusoid. • Determine the natural frequency of a system response in vibration. • Determine the damping of a system response.	• Analyze sample data finding the equation of the damped sinusoid, the damping coefficient, and the angular frequency. • Each team will collect data using the shake table and the structure created. • Students analyze their team's data in the same manner.	
Day 4	• Create a way to increase damping in a system (house or building).	• Conduct a Skype session with Dr. Cohen at the University of Cincinnati. Dr. Cohen will discuss earthquakes for 10-15 minutes, followed by a brief question and answer session. • In teams, students will research ways to modify their structure to change the damping coefficient.	
Day 5	• Evaluate their idea on how to increase damping through experimentation.	• Students modify their structures and recollect data from the shake table. • Students analyze the data and compare the damping coefficient and angular frequency	**Quiz** Given data, determine the equation of damped sinusoid, the damping coefficient, and the angular frequency. Discuss effect of damper on the values of the damping coefficient and angular frequency.

Table 1. Overview of "Shaking up Pre-Calculus" Lesson.

response, determined the natural frequency and damping coefficient, and discussed the impact these parameters had on the response (see Table 2). Building upon exponential functions which they had studied previously, they learned about damped sinusoids and how they represent the decay of vibrations in a system over time.

Shaking Up Pre-Calculus was initiated with the students building KNEX houses in groups with some design parameters. Once shown a few sample videos of structural testing on a life-sized shake table, they quickly made the connection between what they would do with their houses and a homemade "miniature" shake table (Figure 1). For example, these videos show life-sized structural models of houses that are placed on rectangular platforms driven by actuators to simulate a wide variety of ground motions including those seen in earthquakes. Students then placed their houses on the shake table and turned it on to introduce vibrations. This helped them to physically see the type of response that they would be analyzing mathematically.

Figure 1. Students Testing and Taking Data.

Once the students were able to make a connection from the real-life testing to that which they would be doing in the classroom (here, a mini-shake table that only moved in one dimension), the students learned about the mathematical relationships. With the teacher's guidance, the students were shown how to find the equation of a damped sinusoid and then analyze sample data to find the damping coefficient and the angular frequency. An example of a student using a Go! Motion sensor is given in Figure 2 and sample data from the sensor in Figure 3. The corresponding equation, damping coefficient, and angular frequency are shown in Table 2. Building on prior knowledge, they learned that the equation for a damped sinusoid is the product of a sine/cosine wave and an exponential decay curve. The parameters of this function are closely tied to physical terms engineers use to describe a system under vibrations. Therefore, the students learned about the concepts of natural frequency and damping coefficient. They then took data from their own KNEX houses and found these parameters in the same fashion.

The final part of the lesson included a guest speaker, Dr. Kelly Cohen from the University of Cincinnati, who conducted a Skype session with the class to speak about the importance of studying earthquakes, the damage they cause, the basic concept of vibrations, natural frequency, and damping coefficient. This helped to refresh students on the bigger picture and prepare them for the final phase of the project. That is, students where then able to bring an item in from home to put on their house that they thought might reduce vibrations (e.g. put more supports on each member

Figure 2. Students Using a Go! Motion Sensor to Collect Data.

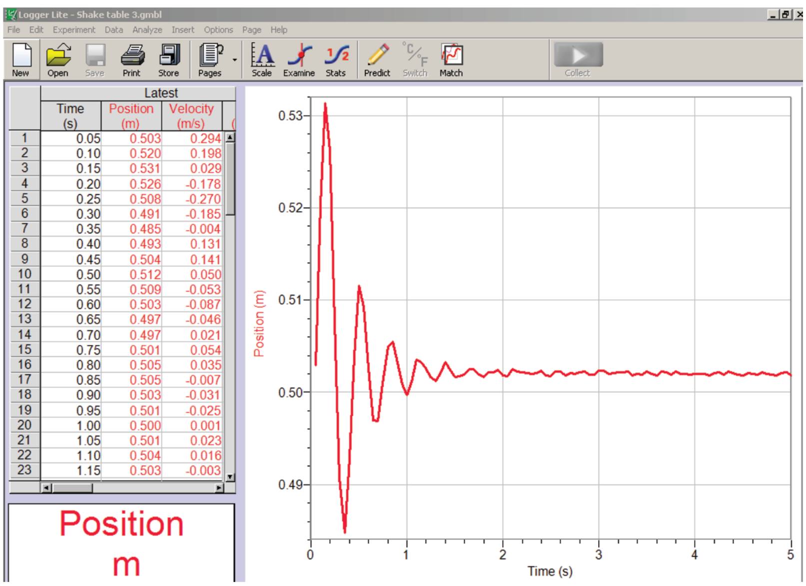


Figure 3. Data Example using Go! Motion Sensor of a Damped Sinusoid.

Line Equation:	$f(x) = 0.029 \cdot e^{-3.04 \cdot x} \cdot \cos(17.952 \cdot x)$
Damping Coefficient:	$\rho = 0.172$
Angular Frequency:	$\omega = 17.693$

Table 2. Corresponding Equation, Damping Coefficient, and Angular Frequency for Figure 3 Example Data.

of the structure, spring, etc). Students then tested their house again on the shake table with the motion detector. Finally, the students analyzed their new data to find their new natural frequency and damping coefficient to see if they improved their home design, and everyone discussed as a group what worked and didn't work and why.

Applications, Careers, and Societal Impact (ACS)

An important aspect of any lesson plan, whether intentionally designed to incorporate engineering design or not, is the inclusion of connections to real-life that students can relate to and to possible careers. This lesson discussed the following applications, career connections, and societal impacts throughout the activities (Table 3).

Ohio Educational Standards Met

Because this lesson was implemented in Ohio, it was required to satisfy the Ohio Academic Content Standards (www.ode.state.oh.us). *Shaking Up Pre-Calculus* discussed Ohio standards in Mathematics and Science (Table 4 and Table 5). While these standards are particular to Ohio, many of these are consistent across states and in the Next Generation Science Standards

	Examples		
Applications	• Buildings • Airplane Wings • Sound Waves	• Light • Earthquakes • Washing Machine Motors	• Shock Absorbers on Cars • Vibration Isolators • Many, many more!
Careers	• Earthquake Engineers • Architects • Civil Engineers	• Aerospace Engineers • Electrical Engineers	• Material Engineers • Mechanical Engineers
Societal Impact	• Engineers can design materials to alter their natural frequency and damping when under different loading situations (e.g. airplane wings are constantly under different loads causing vibrations).	• Engineers can make buildings safer in earthquake regions.	• Engineers can reduce noise caused by vibrations (e.g. planes).

Table 3. Examples of Applications, Careers, and Societal Impact.

Measurement	Benchmark 2.A: Explain the differences among accuracy, precision and error, and describe how each of those can affect solutions in measurement situations. (Grade 11) Benchmark 2.B: Apply various measurement scales to describe phenomena and solve problems.
Patterns, Functions and Algebra	Benchmark 4.A.11: Describe how a change in the value of a constant in an exponential, logarithmic or radical equation affects the graph of the equation. (Grade 11) Benchmark 4.H: Solve systems of linear equation involving two variables graphically and symbolically. (Grade 10).
Data Analysis and Probability	Benchmark 5.A: Create and analyze tabular and graphical displays of data using appropriate tools, including spreadsheets and graphing calculators. (Grade 11)
Statistical Methods	Benchmark 5.A.4: Create a scatterplot of bivariate data identify trends, and find a function to model the data. (Grade 11)
Mathematics Processes	Benchmark 6.J: Apply mathematics modeling to workplace and consumer situations, including problems formulation, identification of a mathematics model, interpretation of solution within the model, and validation to original problem. (Grade 11)

Table 4. Ohio Mathematics Standards Addressed in Shaking Up Pre-Calculus.

(NGSS), which help to give context to the benchmarks accomplished by the lesson. The NGSS are structured around the three dimensions of practices, crosscutting concepts, and disciplinary core ideas. The National Research Council Framework (NRC, 2012), on which the NGSS are being built, firmly relies on two complementary pillars including: 1) Science is an evidence-based base of knowledge and 2) Science is a theory building enterprise. The Ohio STEM standards described

Science and Technology	Benchmark A: Explain the ways in which the processes of technological design respond to the needs of society (Grade 10). Benchmark A.3: Explain why a design should be continually assessed and the ideas of the design should be tested, adapted and refined (Grade 10). Benchmark A.3: Research how scientific inquiry is driven by the desire to understand the natural world and how technological design is driven by the need to meet human needs and solve human problems (Grade 12).
Scientific Inquiry	Benchmark A: Participate in and apply the processes of scientific investigation to create models and to design, conduct, evaluate and communicate the results of these investigations (Grade 10). Benchmark A.4: Draw conclusions from inquiries based on scientific knowledge and principles, the use of logic and evidence (data) from investigations (Grade 10). Benchmark A.3: Design and carry out scientific inquiry (investigation), communicate and critique results through peer review (Grade 11). Benchmark A.2: Derive simple mathematics relationships that have predictive power from experimental data (e.g., derive an equation from a graph and vice versa, determine whether a linear or exponential relationship exists among the data in a table) (Grade 12).
Scientific Ways of Knowing	Benchmark C.11: Research the role of science and technology in careers that students plan to pursue. (Grade 11)
Design	Benchmark: Understand and apply research, innovation and invention to problem-solving. Benchmark: Recognize the role of teamwork in engineering design and of prototyping in the design process.

Table 5. Ohio Science Standards Addressed in Shaking Up Pre-Calculus.

in this paper (Table 4 and Table 5), and used in *Shaking Up Pre-Calculus*, fit into the conceptual framework of the NGSS.

RESULTS AND ANALYSIS

Because of the success of the lesson in the first year, this lesson was repeated for a second year where additional assessment data was taken. In the first year, 21 students were taught, and in the second year, 29 students were taught in various Pre-Calculus classes all instructed by Ms. Childers. The data collected included: 1) pre- and post- assessment results from the first year, 2) student feedback forms from the first and second years, and 3) participant reflections from the first year of implementation. The corresponding results are presented in this section.

Assessment Results

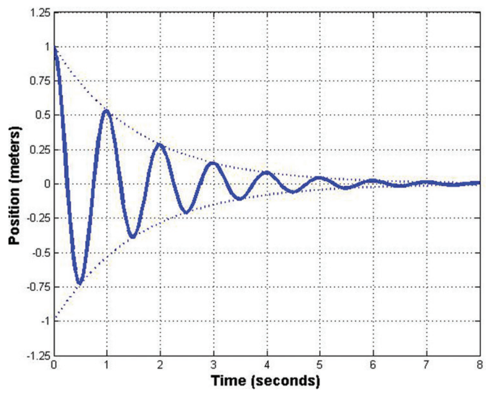
The pre- and post- assessment questions were identical and given prior to the start and after the completion of this lesson in the initial year it was presented. The following year this was left out as other forms of assessment were given. The assessment for the first year consisted of two questions with multiple parts:

Question 1 - Use *t (time)* as the independent variable and *X (meters)* as the dependent variable in the following:

A. What is the general form for a sine function?
B. What is the general form for a cosine function?

Question 2:

Use the following graph to help you answer the questions:



A. Give the **general form** of the equation for the response seen in the graph.
B. Determine the natural frequency of the response.
C. Determine the damping coefficient of the response.
D. Give **the exact equation** for the response seen in the graph.

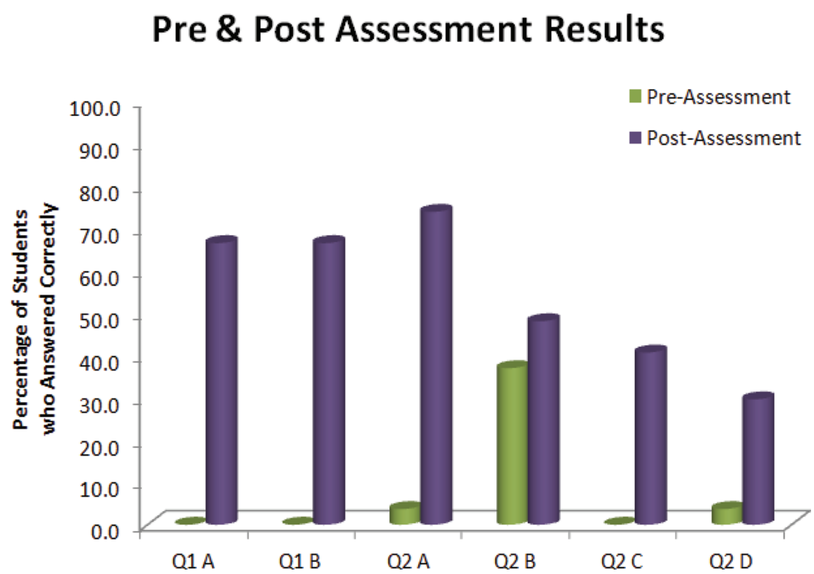


Figure 4. Pre- and Post- Assessment Results.

Prior to the lesson, students were generally unable to complete most, if any, of the assessment. While most of this was due to the fact that they hadn't heard of the terms used in the lesson, they also were unable to put together the mathematics portion. It is clear from the data (Figure 4) that there was a huge improvement in the ability to complete the assessments. Though overall the students improved, there is some subjectivity in the accuracy of this data. That is, these assessments may not have been an accurate reflection of what the students knew prior or learned after. The students expressed that they knew little when completing the pre-assessment and therefore, put forth minimal effort on the problems. The students were engaged throughout the lesson, and they completed the problems in class and this translated into leaning STEM content. Additionally, a common student misconception reflected in the assessments was the difference in the 'general' form versus the 'simplest' form for sine and cosine waves. The question asked for the general form, and since the students first learn the simplest form, many mistakenly used that form instead.

Student Feedback Forms

In addition to a pre- and post- assessment for student comprehension, student feedback forms were given to each student at the end of the lesson for two years to get a clearer picture of the impact of *Shaking Up Pre-Calculus* (Figure 5).

Because the lesson was revised in the second year and differences among classes are always present, both years are reported separately. As discussed earlier, the lesson was altered to make

Student Feedback for Projects RET/STEP 2009-2010

I. Please fill in the information in the box below

Date:	Period:	Lesson:
Grade:	Teacher:	School:

II. Please rate the following statements:

Item	Excellent	Good	Average	Fair	Poor
1. Overall, I would rate this lesson as…					

Item	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
2. I liked the activities we did in this lesson.					
3. The lesson was very well organized.					
4. The teacher was able to explain the subject very easily.					
5. The teacher encouraged us to ask questions.					
6. The teacher was very good at answering our questions.					
7. The group work was very interesting.					
8. I learned a lot from this lesson.					
9. I learned a lot from the teacher.					
10. This lesson made me interested in learning more about Engineering.					
11. This lesson helped me feel more confident about studying math.					
12. This lesson helped me feel more confident about studying science					
13. The lesson was different from other lessons I've had in this class.					

14. How was the lesson **different** from other lessons?

15. What did you like **most** about today's lesson?

16. What did you like the **least** about today's lesson?

Figure 5. Blank Student Feedback Form.

solid connections to current learning objectives of the course and incorporate more accountability. Other differences included the absence of a graduate engineering student the second year (the teacher implemented the lesson on her own) and the interaction with the guest speaker that was conducted on Skype (instead of in person).

School Year #1 (2009-2010) Results

The results from the student feedback forms for the first year are presented in Table 6. Data shows that 100% of the students rated this lesson favorably (excellent, good, or average), and 85% of the students rated it above average. These results are similar to the other questions which ask students to reflect upon their feelings of the lesson. Specifically, 95% of students gave an above average rating for both the activities in the lesson and the group work, 80% stated they "got a lot" from this lesson, and 100% said the lesson was "different from others." When asked if they felt the lesson increased their confidence in studying mathematics and science, results were very similar with about 90% and 80%, respectively, reporting favorably. Finally, students were asked whether this lesson increased their interest in engineering with 90% reporting favorably and 67% reporting above average. Those results discussed above are in bold in Table 6.

Item	Excellent	Good	Average	Fair	Poor
1. Overall, I would rate this lesson as…	**33.33%**	**52.38%**	**14.29%**	0.00%	0.00%
Item	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
2. I liked the activities we did in this lesson.	**38.10%**	**57.14%**	4.76%	0.00%	0.00%
3. The lesson was very well organized.	14.29%	57.14%	19.05%	9.52%	0.00%
4. The teacher was able to explain the subject very easily.	23.81%	38.10%	28.57%	9.52%	0.00%
5. The teacher encouraged us to ask questions.	57.14%	42.86%	0.00%	0.00%	0.00%
6. The teacher was very good at answering our questions.	33.33%	52.38%	14.29%	0.00%	0.00%
7. The group work was very interesting.	**66.67%**	**28.57%**	4.76%	0.00%	0.00%
8. I learned a lot from this lesson.	**42.86%**	**38.10%**	19.05%	0.00%	0.00%
9. I learned a lot from the teacher.	42.86%	38.10%	14.29%	4.76%	0.00%
10. This lesson made me interested in learning more about Engineering.	**19.05%**	**47.62%**	**23.81%**	4.76%	4.76%
11. This lesson helped me feel more confident about studying mathematics.	**14.29%**	**42.86%**	**33.33%**	9.52%	0.00%
12. This lesson helped me feel more confident about studying science	**14.29%**	**42.86%**	**23.81%**	19.05%	0.00%
13. The lesson was different from other lessons I've had in this class.	**66.67%**	**33.33%**	0.00%	0.00%	0.00%

Table 6. School Year #1 Student Feedback Form Results (n= 21).

School Year #2 (2010-2011) Results

The results from the student feedback forms for the second year are presented in Table 7. Data shows that 100% of the students rated this lesson favorably (excellent, good, or average), and 94% of the students rated it above average. Again for this year, these results are very similar to the other questions which ask students to reflect upon their feelings of the lesson. That is, 91% of students gave an above average rating for the activities in the lesson and 82% the group work, 82% stated they "got a lot" from this lesson, and 91% said the lesson was "different from others." When asked if they felt the lesson increased their confidence in studying mathematics and science, results were very similar with about 88% and 79%, respectively, reporting favorably. Finally, students were asked whether this lesson increased their interest in engineering with 58% reporting favorably and 31% reporting above average. Those results discussed above are in bold in Table 7.

Item	Excellent	Good	Average	Fair	Poor
1. Overall, I would rate this lesson as…	**21.21%**	**63.64%**	**6.06%**	0.00%	0.00%

Item	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
2. I liked the activities we did in this lesson.	**39.39%**	**51.52%**	3.03%	6.06%	0.00%
3. The lesson was very well organized.	3.03%	42.42%	39.39%	12.12%	3.03%
4. The teacher was able to explain the subject very easily.	15.15%	39.39%	33.33%	9.09%	0.00%
5. The teacher encouraged us to ask questions.	66.67%	21.21%	9.09%	0.00%	0.00%
6. The teacher was very good at answering our questions.	33.33%	45.45%	18.18%	3.03%	0.00%
7. The group work was very interesting.	**36.36%**	**45.45%**	15.15%	3.03%	0.00%
8. I learned a lot from this lesson.	**30.30%**	**51.52%**	15.15%	3.03%	0.00%
9. I learned a lot from the teacher.	30.30%	51.52%	15.15%	3.03%	0.00%
10. This lesson made me interested in learning more about Engineering.	**12.12%**	**18.18%**	**27.27%**	36.36%	6.06%
11. This lesson helped me feel more confident about studying mathematics.	**12.12%**	**30.30%**	**45.45%**	12.12%	0.00%
12. This lesson helped me feel more confident about studying science	**9.09%**	**18.18%**	**51.52%**	21.21%	0.00%
13. The lesson was different from other lessons I've had in this class.	**57.58%**	**33.33%**	9.09%	0.00%	0.00%

Table 7. School Year #2 Student Feedback Form Results (n= 29).

Discussion

It was evident from the student feedback forms that overall the high school students enjoyed this lesson. Leaving out questions that were specific to the teacher, the results that summarized the students' opinions of the lesson are presented in Figure 6. These highlighted results represent how the students felt about the activities and group work (questions 1, 2, 7, 8, and 13), their interest in learning more about engineering (question 10), and their confidence in studying mathematics and science after this lesson (questions 11 and 12). It can be seen in Figure 6 that *Shaking Up Pre-Calculus* had an extremely high favorability rating with very few students answering any of these questions negatively (disagree or strongly disagree). Not surprisingly, student interest in STEM increased because of the lesson, and with this insight, two student feedback form questions became extremely important. For both years, students rated 2 questions as excellent. The first, "the teacher encouraged us to ask questions", points out that the students were truly in an inquiry project. The second, "the lesson was different from other lessons I've had in this class", explains the importance of hands-on activities in mathematics (and all STEM) classes.

By focusing on students' responses to the varied activities and group work, it was clear students were interested in the STEM content and enjoyed having a different task for each day of the lesson.

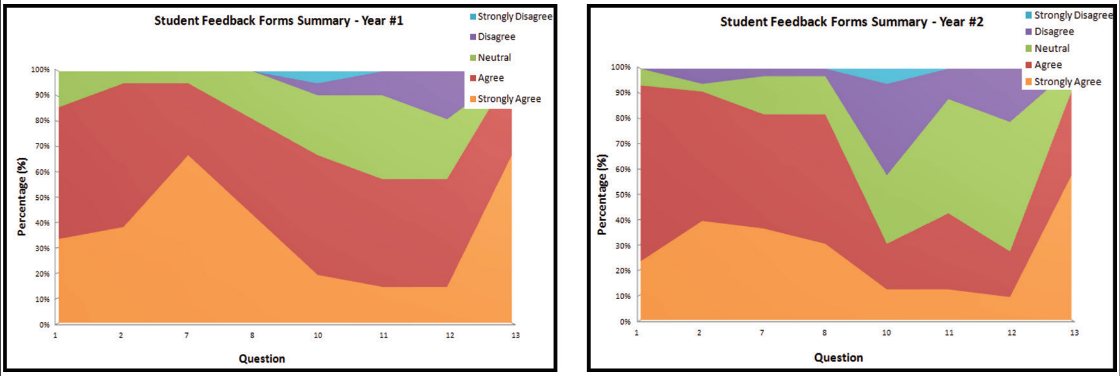


Figure 6. Student Feedback Form Results Summary.

While this can partly be attributed to the novelty of the lesson, this is also simply an outcome of these types of lessons (inquiry projects, problem based learning, and active learning). By providing students with a variety of activities, students break out of their normal routine and become actively engaged in their own learning. The more prevalent these lessons are in everyday learning, the stronger the response of the student to indicate an overall positive correlation between these types of lessons and student engagement.

While these strong positive results were not typical of every lesson implemented through Project STEP, this lesson highlights how a well-organized and thought-out plan can positively impact students. Not only did students *enjoy* this lesson while it was taking place, student feedback forms suggest that the effect of this lesson may extend well beyond the school year. With an increased confidence in studying mathematics and science, students may perform better at higher levels. Furthermore, students were introduced to new concepts in engineering, many fields of application, and careers related to the concepts. It is difficult to meet all the objectives in one learning module, but engineering design lessons show that teacher and scientist partnerships can encourage positive STEM engagement for students. Additionally, *Shaking Up Pre-Calculus* shows that students are receptive to, benefit from, and genuinely enjoy classes that integrate STEM course material with real-life applications and make career connections.

By just focusing on the responses to questions about interest in engineering, mathematics, and science, these strong results show how just one lesson can help shape a student's view on a subject. It is difficult to say whether this is a lasting effect without further or more long-term studies, and this is an area that needs future work. For example, there is a decrease in positive responses in the second year of reporting. It is hard to explain the cause based on the limited data. Possibilities include the extra time spent on the lesson during the first year, having the guest speaker and graduate engineering student both directly in the classroom during the first year, and/or just the particular group of students (either the first year or the second). However, the authors of this paper believe that students regularly engaged in active learning activities that give them a positive experience with engineering, mathematics, and science will be more likely to consider a STEM career later in life.

Lesson Reflections

Graduate Engineering Student View

It was clear that *Shaking Up Pre-Calculus* was able to reach students beyond traditional course work. For the majority, the students grasped the lesson and objectives and this was reflected throughout the classroom activities and discussions. Additionally, they understood the importance of studying the different mathematical concepts presented in the lesson, because the lesson's core was tied to real-life applications. In fact, many of the student feedback forms reflected the genuine interest of the students. Since the lesson was about vibrations, the students and graduate engineering student discussed multiple uses and interests of engineers across multiple disciplines. Students were encouraged to discuss and participate during class, and therefore, they were truly engaged throughout the whole lesson and consistently asked relevant questions. For example, they wanted to know beyond Earthquake Engineering where these concepts would apply. The teacher and graduate engineering student were able to discuss the issues and make connections to many applications including: buildings, airplanes, bridges, cars, etc.

While most of the students enjoyed the lesson, a few students mentioned that they had difficulty with the material. Most of the challenge was due to abundant, new vocabulary and concepts that were presented quickly. Unfortunately, the time it took to work through examples was underestimated. Therefore, the lesson took a week longer than originally planned, and the instructor moved rapidly through the remaining material. However, when the students understood the concepts and those concepts "clicked," it seemed like they had a true sense of accomplishment due to the higher difficulty of the material they had mastered. Student understanding was evident when a student brought in her own object and added it to her house for a damper. Once she could see the difference in the response (or not see the difference depending on the "damper" she chose), she acquired a clearer picture of the lesson's purpose.

Classroom Teacher's View

From a mathematics teacher's perspective, it was important to have projects in which the majority of the lesson was dedicated to advancing the mathematics knowledge of the students while spending a proportionally smaller amount of time discovering the new mathematics concepts. It was also important to make sure that connections were made with previously learned mathematical concepts. To make the time spent worth the effort, the students had to realize that the mathematics learned had appreciable applications. *Shaking Up Pre-Calculus* had all of these elements.

Upon the completion of this lesson, the students understood the meaning of a damped sinusoidal function and modeled the damped sinusoidal function from the collected data. It was within the creation of the damped sinusoid that the students used the previously learned concepts of exponential growth (or decay) and solving systems of equations.

The parts of the lesson that the students found most exciting were the building of a structure as a team out of KNEX and the use of technology for the collection and analysis of the data. The data was collected using a GLX for motion detecting and then transferred to the TI-Nspire CAS handheld to be graphed and analyzed. The students had previously learned how to create a scatter plot from collected data so plotting data that they collected from their own structure was a meaningful review. They then worked to find an equation of a damped sinusoid by hand, without using a regression equation in the TI-Nspire, and then graphed the equation they found directly onto their scatter plot. This gave them immediate feedback about whether they had indeed found an equation that closely fit the data they collected.

Ms. Childers also was able to show the students a few sample videos on YouTube that showed actual structures and their damping systems by using resources introduced to her by the graduate engineering student. This was a beneficial means of getting the students to start thinking about what type of damper they could use to modify the structures that they had built. Because each student had their own tablet computer, they immediately researched different types of dampers and discussed and compared what might work best. Students appreciated being able to make decisions about how to modify their structures and measuring the effect of the modification.

As mentioned earlier, during the course of the project, Dr. Cohen, a professor from the University of Cincinnati, made a short visit to the classroom to talk about the physical features of earthquakes, the ramifications of the destruction caused by the earthquakes in the insurance business, and the need for engineers to search for feasible solutions to prevent serious damage to structures. The second year in which this lesson was taught, Ms. Childers used Skype to connect with Dr. Cohen for a 15 minutes conversation with her students. Since using Skype was a relatively new tool in a classroom, the students were quite excited by how easy it was to use and by the chance to connect with an expert in the earthquake field. His image was projected onto a large screen and his voice through classroom speakers. He effectively captured their attention with interesting thoughts regarding earthquakes and by making connections with recent severe earthquakes covered by the media. The students felt comfortable asking questions, and their curiosity about earthquakes was piqued.

Ms. Childers expected the first presentation of the project to be a trial run that would be modified. The authors had an expectation that revising parts of the lesson would occur once the first run-through was completed. First, the lesson took too much time to complete. The authors condensed the lesson from eight days to five, as five days of curriculum concentrating on one particular project was the maximum amount of time allowable. Secondly, the teacher and graduate engineering student presented mathematics concepts and then added homework assignments to help the students internalize the topics.

This is currently a favorite lesson for the students and Ms. Childers. It meets the learning objectives set forth in the Ohio Standards and the students enjoy, and appreciate, being involved in a lesson that has real-world STEM applications.

High School Student's View

The student's view was solicited in the form of the student feedback form questionnaire. Students were asked to reflect upon how the lesson was different from others, what they liked about the lesson, and what they didn't like about the lesson. To supplement the student feedback forms, several students provided additional feedback about the lesson. These were in the form of direct quotes and are as follows:

> "I enjoyed the project because it showed me how what I was learning can be used in everyday life." –Shanna

> "I loved how it applied material from various subjects (physics and mathematics) and the project being interactive with diverse technology such as the motion detector." –Nicole

> "I really enjoyed the lesson taught by Ms. Sabo. My class often talks about how the information from our lessons is used by particular people and professions but we rarely get to test the lessons taught to us with hands-on activities. This lesson allowed us to investigate the issues involved with buildings and earthquakes with a hands-on activity. Ms. Sabo was able present the material in a manner that was understandable and still able to explain the complex theories and equations." –Danielle

> "I really liked the project because it helped apply the damped sinusoid equation to real life. Seeing a crazy equation in a practical situation was very cool." –Emma

Overall, many of the student feedback forms and the quotes reflect the students' interest in the *Shaking Up Pre-Calculus* and their enjoyment using the mathematical concepts in real-world problems. Since this STEM lesson was about vibrations, the students, classroom teacher, and graduate engineering student discussed multiple applications of the concepts for engineers across many disciplines. The students made the connections to buildings, airplanes, bridges, cars, and the like. Therefore, the students had many applications to discuss and further their interest in engineering. Other good feedback from the forms showed that students really enjoyed the hands-on work.

Most comments from students regarding what they disliked about the lesson touched on the difficulty of the concepts and the lack of outside course materials to use as resources. They mentioned that the lesson was very confusing at first, and they found using Greek letters in their equations to be difficult. While the students seemed confused at first, by the end of the lesson most students put concepts together and were proud of themselves for doing so. Moreover, the confusion was expected since a majority of these students did not have a clear picture of engineering tasks before the lesson, let alone have seen the types of problems they might work to solve.

One student's answer to what she liked least about the lesson was a good summary of the *Shaking Up Pre-Calculus'* success:

"I would've liked to do a second structural change."

While it is a seemingly simple comment, it says volumes. Not only did this student understand the mathematical relationships and that the changes she made to dampen (or improve) her structure could have been enhanced, she actively wanted to keep working to problem-solve and explore other ideas. The desire to learn more is the epitome of what it means to be a good researcher and engineer: knowing that not everything will work and sustaining the enthusiasm to keep trying. Even though this is one student example, it is reflective of the group. Students were interested and engaged, and whether they believed it or not, they all have attributes of engineers.

CONCLUSIONS

Overall, *Shaking Up Pre-Calculus* was exceedingly successful: student learning was extended beyond the traditional curriculum by combining previously learned concepts with real, newly developed, and exciting applications in technology. Previously learned concepts included plotting and modeling with exponential functions, solving systems of equations, graphing of sine and cosine functions, and more. The lesson was a guided inquiry activity that involved structured student guidance through teacher-presented questions with multiple correct procedures and answers. Lesson from inquiry projects, project-based learning, and active learning literature were all used in the development of the *Shaking Up Pre-Calculus* lesson. Results from assessments showed a significant improvement in student knowledge gains as students' scored nearly 0% correct on pre-tests but 50-70% correct on post-tests showing that the students grasped the lesson and objectives.

By applying engineering concepts, synthesizing their own KNEX house and damping effect, and predicting and evaluating the outcome of the structural changes, the students gained a deeper understanding of the course materials. This is partly due to the higher-level learning objectives that integrating engineering inevitably causes. Integrating engineering into curricula also helps to facilitate STEM inquiry-based, project based learning, and active learning as these are integral parts of the engineering design process. Also by discussing the engineering applications, careers, and societal impacts, students showed that there was an increased interest in STEM fields.

Lessons in engineering, which include all STEM topics, are engaging for students as well as the teachers. Data and feedback also showed that students appreciate the engineering connections and the activities designed around them. The students were engaged throughout the whole lesson and were consistently asking questions that indicated their involvement in the material. Most of the students agreed that they were encouraged to ask questions and that this lesson was different from most of the other mathematics lessons from Ms. Childers (Table 6 and Table 7).

Due to the practicality of implementing and integrating these lessons in high school classrooms, limited reporting is obtained in the form of pre- and post- assessments and student feedback forms. However with the pre/post tests and student feedback forms, the authors showcased the impact of these lessons on student interest in content and in STEM. For all of the Project STEP lessons, student feedback forms that were filled out by the students (n=~3000) after the Project STEP lessons demonstrate that on average 40% of the students increased their interests in STEM content and STEM careers after the lessons. For the Earthquakes and Engineering lesson (*Shaking Up Pre-Calculus*), 74% showed increased interest in engineering, and 89% and 80% showed increased confidence in studying mathematics and science, respectively.

The data acquired shows promise that student interest in STEM fields can be increased. It is also possible to foster this interest while meeting educational standards and working within the time constraints of demanding curricula. There are many resources available to teachers today that allow them to do this more easily. These include websites dedicated to lesson plans with engineering content (similar to the STEP website), engineers in the community and at local universities and colleges, and many volunteers that dedicate their time to outreach in primary and high schools. Again, all Project STEP (http://www.ceas3.uc.edu/step/main_pages/index.html) lessons are detailed in full on the website so teachers (and other interested parties) can easily download and implement them. Additionally, there are other similar websites with detailed lesson plans for use by teachers. Other educators can also find these resources useful like those focused on outreach projects or those within the engineering education community. However, many will find a need to tailor activities/projects for their own use. To do this successfully, several items need to be accomplished: material needs to be relatable (i.e., earthquakes in this particular lesson), learning objectives need to be clear and tied directly to the 'relatable' concept (i.e. vibrational analysis to sine/cosine waves and exponential decay), projects should engage your students in learning (inquiry projects, project based learning, inactive learning, etc), and an assessment needs to be given to evaluate effectiveness and validate concepts (e.g. tests, discussion, project, homework, demonstration, etc).

The authors of this paper provide evidence that the students enjoy, and benefit from, lessons that are formulated around activities and real-life examples. Students want to become involved with STEM lessons that have real world applications, specific career connections, and questions regarding societal impact. *Shaking Up Pre-Calculus* was a successful validation of this ideology. Satisfied students are just a bonus of the content heavy, but fun, activities that engineering allows.

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