Effective Approaches For Teaching STEM-Literacy To Non-Engineers

Princeton University
INTRODUCTION

STEM education should not be focused solely on producing STEM professionals. Universities educate students who often transition into leadership positions in government, education, civic administration, law and business, with significant influence in society. Thus it is our obligation to graduate students who can question, think, and analyze for themselves, and are scientifically and technically literate. Recognizing this, most universities require non-STEM students to take at least one STEM class.
The American Society for Engineering Education concurs by stating that “Engineering colleges should accept responsibility for providing technical literacy programs to liberal arts students.”\(^1\) And the NAE report, “Educating the Engineer of 2020”\(^2\) states: “It is in the enlightened self-interest of engineering schools to help the public understand what engineers do and the role that engineering plays in ensuring their quality of life. Moreover, a country weak in technological literacy will have increasing difficulty competing in the technology driven global economy of the 21st century. Thus we recommend that the engineering education establishment should participate in a coordinated national effort to promote public understanding of engineering and technology literacy of the public.”

At Princeton University, two engineering courses that have been taught for decades to meet this objective of educating non-engineering majors about engineering. Each course enrolls on average 125 to 150 students per year, and 75% or more of those students are non-engineering majors. The first introductory course called “Structures and the Urban Environment”, begun in 1974, traces the development of structural engineering through case studies of outstanding
What is Active Learning?

Active Learning is anything that students do in a classroom other than merely passively listening to an instructor’s lecture. Research shows that active learning improves students’ understanding and retention of information and can be very effective in developing higher order cognitive skills such as problem solving and critical thinking. The goal of this project is to reduce the attrition of STEM students by utilizing student-active pedagogies (student-to-student and student-to-teacher) that have been proven effective in promoting retention and cultivate an appreciation for the role of engineering in everyday life.
Students interact with simple paper models during an interactive lecture demonstration.

For additional examples of active learning exercises see: casce.princeton.edu/active-learning.html
research-based pedagogical techniques were introduced in the lectures and recitations. Research has shown that delivering the course with such techniques (e.g., interactive techniques - student-to-student and student-to-faculty) was by far the most important influential positive factor in a student’s development. These research-based techniques demonstrate improved student attitudes and led to a higher level of knowledge acquisition (they remembered and comprehended more). [3, 4, 5, 6] This interactive approach is significant for all teaching, no matter who the audience; but the authors posit that it may be even more significant for teaching non-engineering majors, where the students in this case may not have a solid background in core concepts related to engineering (e.g. physics) and may even have negative affect towards engineering or low self-efficacy (i.e., enter with the attitude of ‘I am not sure I can do this’). For example, in the first lecture of the course, using online polling, the instructor asks “What do you expect to be the greatest challenge in this class?”. Partial responses are shown in Figure 1, where it is seen that “physics” comes up often, as do other anxieties. Although not shown, “math” is another popular response, as are the laboratory components of the course.
As of May 2016, we have modified 85% of the course lectures to make use of active learning pedagogies, such as interactive lecture demonstrations, hands-on activities, polling questions, and discussion questions. We are continuing to work towards developing further interactive teaching exercises for this course. Previous conference papers by the authors have illustrated some examples of effective teaching approaches. For example, [7] discusses some kinesthetic activities, [8] discusses effective practices using online polling, and [9] discusses effective interactive methods for teaching reinforced concrete. This paper specifically focuses on interactive lecture demonstrations (not just ‘plain’ lecture demonstrations). An example of such a demonstration is provided to teach concepts of resonance in buildings for earthquake performance.

**Resonance Resonates: Predict, Experience, Reflect**

An effective approach for implementing an interactive lecture demonstration involves three stages: predict, experience, and reflect [10]. This Section defines each stage and how it was executed in a lecture with the objective of teaching students about resonance in buildings during an earthquake.

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**What do you expect to be the biggest challenge?**

- “building the bridges”
- “coming to class”
- “exams and doing the readings”
- “lecture seat”
- “attending lab”
- “building a bridge.”
- “the reading”
- “understanding structural concepts”
- “number of seats”
- “physics”
- “10 am”

*Figure 1. Student responses to their perception of greatest challenge.*
Which of these “buildings” will shake the most in an earthquake?

In a study by Crouch et al. \cite{11}, it is shown that students who just passively observe a demonstration do not have a better understanding of the subject than students who do not observe the demonstration at all. However, involving students by asking them to predict the outcome of the presentation yields a better understanding. With this concept in mind, students were asked to predict which “building” would sway the most in an “earthquake” (see Figure 2). The word “building” is in quotes because it is represented by a wooden block on top of a threaded rod. Four blocks of the same size are each attached on top of 4 threaded rods of different heights. This teaching tool is called the Building Oscillation Seismic Simulation (BOSS) model, a pedagogical physical demonstration developed by the American Geophysical Union and revised by the Incorporated Research Institutions for Seismology (IRIS) consortium \cite{12}. Since the blocks are all the same weight, the only difference between the four “buildings” is the stiffness, as represented by the heights. All four “buildings” are placed on a two-by-four, which is mounted on a set of wheels.

Figure 2. Simplified BOSS model teaching tool.
With Figure 3 projecting on the screen, the instructor then shakes the base with a frequency to excite Building 4 (or 3 or 2), which no one selected. The response of the students is literally an audible ‘gasp’ as students express their surprise at the outcome. Shaking the model to excite the frequency of Building 4 is the most dramatic, as it is the shortest building and most students predicted that the tallest building would move the most. The literature shows that learning by being surprised (disconfirmation) is very effective\cite{13}, as such ‘discrepant events’ highlight a mismatch between students’ observations and their prior expectations, and therefore generate interest. To further the demonstration, the instructor shakes the base to excite Buildings 1, 2, and 3, one at a time. As one student put it in the class evaluations, the demonstration was a form of “magic”: “I will never forget the idea of resonance in skyscrapers...because of the wonderful demo... It was amazing watching different blocks move with different frequencies... (seemed like magic!).”

With their attention and curiosity captured, one can then present the equation and physics behind the “magic”. Figure 4 shows the slide information that
follows the interactive demonstration with the relevant equation. It can thus be explained that ‘resonance’ happens when the natural period of vibration of the building, which is calculated with the equation shown, matches the frequency of ground shaking. The next step is for them to experience resonance on their own.

**EXPERIENCE**

The course in which this interactive demonstration happens enrolls on the order of 150 students. All of these students can easily experience resonance in their seats (i.e., there is no need to go to a lab) with two pieces of mini marshmallows and two pieces of spaghetti. As shown in Figure 5, the marshmallows are placed on top of the spaghetti, and the spaghetti are held in the hands with two different heights. The student then shakes his/her hand until it resonates with one spaghetti/marshmallow “building”. Then the hands shake at a different frequency until the other spaghetti/marshmallow “building” resonates.

**REFLECT**

In the reflection step, students are presented with a prompt that asks them to apply their understanding

\[ T_n = 2\pi\sqrt{\frac{m}{k}} \]

The only difference between the “buildings” in this example is \( k \).

\( k = \text{stiffness} \)

\( m = \text{mass} \)

for #1 is smaller, therefore \( T_n \) is larger

10 Figure 4. The physics behind the demonstration.
in a novel context. Opportunities for reflection help students apply newly-gained knowledge and consolidate their understanding [4].

In the reflect phase of the interactive demonstration a case study is presented: the 1985 Mexico City earthquake. Figure 6 shows images from a slide used in the class, which asks students to reflect on why most buildings that collapsed during the Mexico City earthquake were between 5 and 15 stories. Once again, online polling is used but this time as an open-ended question instead of multiple choice. The example of 2015 responses is presented in Figure 9 (2016 responses are similar). It is seen in Figure 9 that most students appear to have connected the interactive demonstrations of resonance to a real-world application. They understood that the ground motion period of the Mexico City earthquake was similar to the natural period of vibration of the 5 to 15 story buildings.

Consider that the large majority of the students responding are not engineering students; and consider the anxieties that are partially demonstrated in Figure 1. In less than half-hour these students were able to understand resonance in tall buildings.
“The Mexico City Earthquake caused between 3-4 billion dollars in damage as 412 buildings collapsed and another 3,124 were seriously damaged...”

Most affected buildings were of intermediate height (between 5 to 15 stories).... WHY?

**Figure 6.** Reflect: Using a case study students apply their knowledge to answer a question.

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**Learning Outcomes**

We adapted the *Student Assessment of Their Learning Gains* (SALG) survey [14] in order to measure the students’ self-reported gains in their skills, understanding of the course content, attitudes towards engineering, as well as gains due to various course components (e.g. assigned readings, lectures, hands-on activities). Partial results of this survey are presented in **Figures 7 and 8**, which are for 2016. These results are slightly improved from 2015 (where n = 65).

In 2016, 100% of the students (n = 21) reported great, good, or moderate learning gains due to the lecture demonstrations. Furthermore, a large majority of students reported great, good, or moderate learning gains from the hands-on activities (95%), interacting with peers in class (91%), polling questions (81%), and participating in group work (72%). In addition, when reporting on their attitudes towards engineering, 100% of students (N=21) reported good, great or moderate gains in seeing engineering as a creative profession, enthusiasm for the subject, interest in discussing the subject area with friends or family, and
Figure 7. Survey results pertaining to interactive teaching methods (2016 results shown)
**Figure 8.** Survey results pertaining to gains in student attitudes (2016 results shown)

<table>
<thead>
<tr>
<th>Attitude</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeing engineering as a creative profession</td>
<td>100%</td>
</tr>
<tr>
<td>Possess an aesthetic and technical appreciation for bridges, towers, shells, and other structures</td>
<td>90%</td>
</tr>
<tr>
<td>Enthusiasm for the subject</td>
<td>90%</td>
</tr>
<tr>
<td>Interest in discussing the subject area with friends or family</td>
<td>86%</td>
</tr>
<tr>
<td>Coincidence that you understand the material</td>
<td>76%</td>
</tr>
<tr>
<td>Interest in taking or planning to take additional classes in this subject (ignoring time constraints)</td>
<td>71%</td>
</tr>
<tr>
<td>Willingness to seek help from others (teachers, peers TA) when working on academic problems</td>
<td>67%</td>
</tr>
</tbody>
</table>

![Gains in Attitudes](chart.png)
in possessing an aesthetic and technical appreciation for bridges, towers, shells, and other structures. These results serve to highlight the efficacy of the interactive teaching methods adopted in this project towards improving student learning outcomes as well as attitudes towards engineering. Further details about our evaluation methods and results can be found in the ASEE 2016 conference paper entitled ‘Enhancing Student Cognition and Affect through the Creative Art of Structural and Civil Engineering’ [15].

**Conclusions**

A course that teaches engineering to non-majors as recently been enhanced with active learning pedagogies, such as interactive lecture demonstrations, hands-on activities, polling questions, and discussion questions. This paper presented, specifically, the teaching of resonance in tall buildings with these learning pedagogies. Since non-engineering majors may experience more negative affect towards engineering or lower self-efficacy for an engineering course, these active learning exercises have the potential to be very effective in leveling the playing field. In the example of the course presented in this paper, survey results show great gains in learning as enabled by active learning, and great gains in attitude (e.g., enthusiasm for the subject).

**Figure 9.** Reflect: Open-ended online polling response to ‘reflect’ question
REFERENCES


Dr. Maria Garlock is an associate professor in the department of civil and environmental engineering at Princeton. Her scholarship is in resilient building design for large earthquakes and fires, as isolated and as combined multi-hazard events. In addition, Dr. Garlock studies the best examples of structural designs of the present and past, which encompass the ideals of efficiency, economy, and elegance. She has co-authored a book on the subject with David Billington (Félix Candela: Engineer, Builder, Structural Artist), and co-curated three exhibitions with scale models and instructional displays that teach about exemplary structural engineering designs. She is the recipient of the 2012 President’s Award for Distinguished Teaching, which is the highest teaching award at Princeton. In 2013 she was selected to participate in the National Academy of Engineering’s 2013 Frontiers in Engineering Education Symposium where she discussed the topic of this proposal with colleagues all around the nation.

Dr. Evelyn Laffey is the current Associate Director of the Princeton Council on Science and Technology. Evelyn has a doctorate in mathematics education and bachelor’s in mathematics from Rutgers University. Her research and teaching are focused on providing an excellent and equitable STEM education for all students. Prior to joining Princeton, Evelyn was the Assistant Dean for Engineering Education at Rutgers School of Engineering where she developed engineering education programs to enhance the learning and teaching of STEM. Relevant to this proposal, she lead the team responsible for the implementation of an ENGAGE Faculty-Student Interaction mini-grant and two NSF grants (Robert E. Noyce Teacher Scholarship Program and a Research Experience for Teachers).
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### ABOUT THE PROGRAM

This material was produced for the NSF-funded project “Advancing the Dissemination of the Creative Art of Structural and Civil Engineering” - in developing an engineering course to facilitate STEM education for both engineering and non-engineering undergraduate students.

This project is managed by Princeton University in partnership with the University of Massachusetts (Amherst), and Virginia Polytech Institute.

For more information about the Creative Art of Structural and Civil Engineering

[casce.princeton.edu](http://casce.princeton.edu)
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