GIFTS: Engaging First-Generation, Low-income (FGLI) Students in Engineering through Inquiry-based, Hands-on Activities

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Her scholarly background is in geometric function theory and discrete groups; her current work focuses on engineering education, curriculum design, and broadening access to high-quality STEM education. She has led multiple large-scale educational initiatives, including NSF-funded efforts to integrate data science across the undergraduate curriculum and an AAU-funded STEM Teaching Evaluation Demonstration Project developing more holistic approaches to teaching evaluation.

Professor Bonfert-Taylor has played a central role in creating innovative educational programs at Dartmouth, including the interdisciplinary Green City Foreign Study Program in Berlin and the Dartmouth Emerging Engineers (DEE) program, which supports aspiring engineering students and fosters early community and belonging. She has also contributed extensively to the design of MOOCs and professional certificate programs in C programming, work that earned her team the 2019 edX Prize for Exceptional Contributions in Online Teaching and Learning.

She is a Fellow of the Association for Women in Mathematics and has received numerous teaching and leadership awards, including the 2025 Frank J. Guarini Award for Extraordinary Contributions to Off-Campus Programs.

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Motivation

Through this Great Ideas for Teaching (and Talking with) Students (GIFTS) paper we share an inquiry-based, hands-on approach to introducing and engaging incoming first-generation, low-income (FGLI) students in engineering. Data collected over the past 10+ years indicate that students, a disproportionate number of whom are from FGLI backgrounds, leave engineering in their first year of college, often after taking a mathematics course and before ever taking an engineering course [1], [2]. We hope to reverse this trend by introducing engineering to incoming FGLI students during the summer before they start college.

Background

For the past 5 years, we have been working with 80-90 FGLI students through a 2-week long summer program aimed at helping them transition to college by building a cohort, developing a support network, sampling academic classes, determining where to go for help, and exploring different possible majors. FGLI students from the incoming class are invited to participate in the program, with ~75% of those who were invited to participate joining the summer program. Participants received a stipend to participate.

Two years ago, we revamped the curriculum to incorporate more mathematical concepts; while our intentions were good, the outcomes were mixed to negative [3]. Students found the concepts too abstract and uninteresting [3]. So, we again revised the curriculum this past summer, making it inquiry-based and hands-on, with marble runs as the focus (who doesn't love a marble run?).

Objectives

The emphasis in the summer program was on engineering inquiry-based problem-solving and hands-on activities rather than on mathematical derivations and theory. Research conducted by Felder and Prince [4] indicates that inductive (or inquiry-based) approaches can be much more effective at helping students learn than the traditional deductive approaches favored in engineering. Thus, rather than starting by presenting theories (deductive), inductive (or inquiry-based) teaching starts with a problem, data, or a case to solve, thus engaging and motivating students [5]. Rolston and Cox [6] found that hands-on learning helped to recruit and retain FGLI students.

In an effort to make the material engaging to students from a wide range of backgrounds and interests (not all are planning to major in STEM), we used marble runs as a thread throughout the program. Through the program students:

1. Used mathematics to solve engineering and physics related ramp problems, including loops;
2. Built a laser-cut wooden marble machine, with a spiral ramp;
3. Used breadboards to create an electric circuit to power a marble machine;
4. Reflected on their own learning.

Longer-term goals that we are tracking for the STEM portion of the summer program are to increase retention and self-efficacy in STEM among FGLI students.

Implementation

We introduced derivatives and trigonometry as well as physics principles using ramps and an inquiry-based approach. Students worked in small groups to answer questions, test different ramps, build magnetic marble runs, build laser-cut wooden marble machines, and create breadboarded circuits to power their marble machines. During the two weeks of the program we met with students 3 days a week for 2 hours per session for a total of six sessions. Lecture slides for all of the sessions are available here: 1-Position, Velocity, & Acceleration; 2-Rollercoaster Math & Physics; 3-Marble Run Challenge; 4-Electricity & Breadboarding; 5-Marble Machine Assembly; and 6-STEM@Dartmouth.

Rather than starting with mathematical concepts as we had in the previous year, **Session 1 - Ramps and Motion** started with students experimenting with straight ramps. Teams of students were able to adjust the height of the ramps and experiment with balls of different sizes and weights. While this is a pretty standard physics experiment, we used it as a way to introduce mathematical concepts as well, specifically derivatives by relating speed, velocity, and acceleration. We brought in engineering by discussing why engineers might want to design certain types of ramps (fast roller coasters, for example). Students were also introduced to Vernier Video Analysis tools to analyze videos of balls on the ramps. Vernier Video Analysis is used in physics courses on campus so we hope that by introducing the software we give students some confidence when they take physics courses. We created a series of videos of balls on ramps of different heights to use for the video analysis rather than having teams create their own videos to save time and make sure the videos were fairly clear. Figure 1 shows one of the videos of a ball on a ramp.

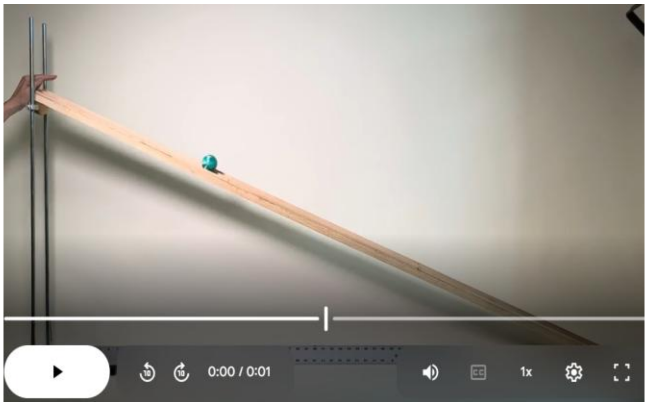

Figure 1. Ramp video

Session 2 - Loops focused on derivatives and loops, beginning with small teams experimenting with MagTrax magnetic marble run components by constructing the set-up shown in Figure 2. Teams were then asked a series of questions: 1) At the very top of the loop, what keeps the marble from falling down? 2) At what height (h_0) do you need to release the marble so that it makes it around the loop? and 3) How does that height (h_0) relate to the radius (R) of your loop? After some experimentation and data collection, we presented theoretical derivations of motion and loops. Students were then able to calculate the theoretical values for loop radius (R) and height (h_0) and compare these theoretical values with their experimental results.

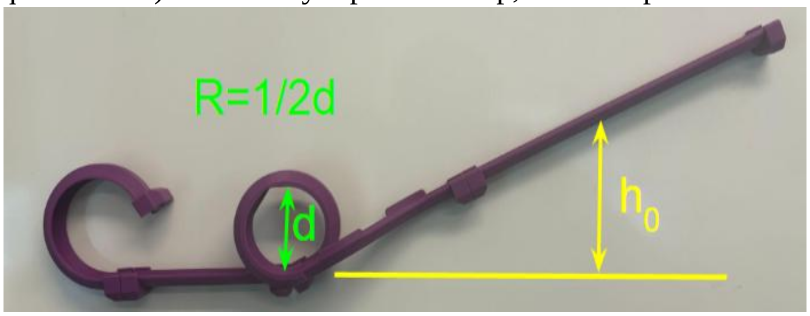

Figure 2. Magtrax loop

During **Session 3 - Marble Runs** students were given full sets of MagTrax components and challenged to build marble runs in small teams: marble runs that were the fastest, longest, craziest, ones that used the most components, included a loop, a jump, etc. Students were also challenged to mathematically predict the time it would take to complete the marble run. Engagement was high in this activity as shown in Figure 3.


Figure 3. Magtrax marble run

In **Session 4 - Breadboarding** students were introduced to electricity and breadboarding and asked to create a range of circuits from a basic LED/battery circuit to one controlled by a switch and circuits that included motors. They were again asked a series of questions related to parallel and series circuits, power vs. energy, etc. and encouraged to answer the questions through experimentation. In addition, they were asked to theoretically calculate resistor values and energy/duration of the batteries. The goal was to give students some experience with circuits and exposure to breadboarding to get them ready to create their own breadboarded circuit to power their marble machines.

During **Session 5 - Marble Machine** each student built a laser-cut marble machine that is powered by batteries and a motor. We purchased marble machine kits that we adapted (we have laser-cut the parts ourselves in the past but it is time-intensive to do so for 100 students). One of the adaptations was to add a breadboarded circuit to battery-power the marble machine. Students first built the circuit and then built the wooden portions of the marble machine; an assembled marble machine is shown in Figure 4. While we'd love to allow customization of the marble machines, this is challenging given the class size, time constraints, and students' varied backgrounds and interests.

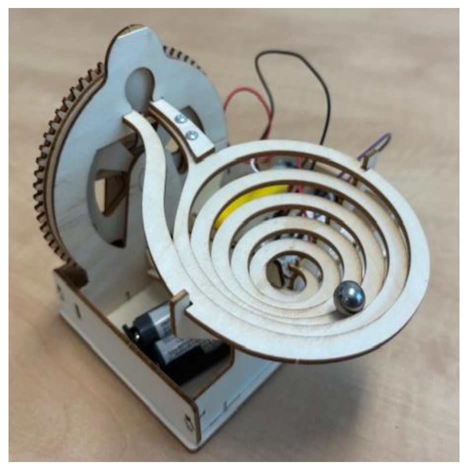
Figure 4. Assembled Marble Machine

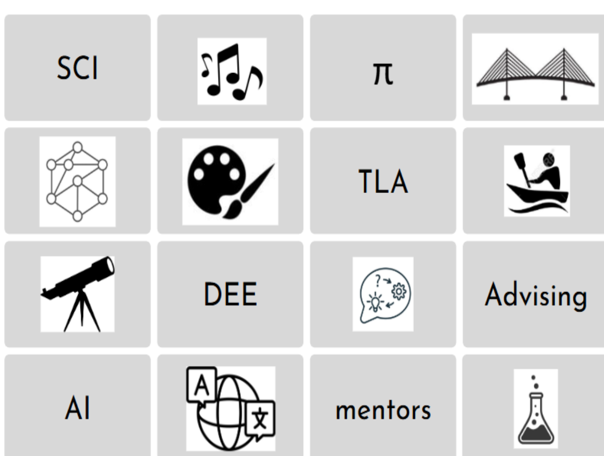

Figure 5. Connections game

During the final session, **Session 6 - Connections**, students were introduced to the STEM curricula across campus through a version of the NYT Connections game as shown in Figure 5. They were then asked to create their own connections related to their experiences with the summer program and to consider how they planned to build connections throughout their academic careers.

Assessment

While students did not receive grades in the summer program, formative assessments were incorporated to measure learning and the effectiveness of the program. In sessions 1 and 2, student teams shared the data they collected and the calculations they performed via a class google sheet. Thus, we could pool the data and at the same time see that each team was getting reasonable results (and if not, help them to correct their procedure). The marble run challenge was intended primarily as a fun activity; however, even during this session, students discussed and reflected on their designs. During the breadboarding activity in session 4, the instructors and teaching assistants worked with teams and individuals to make sure everyone was able to complete a range of different circuits and do some experimenting. Session 5 was successful in that all students were able to build a functional marble machine. Finally, to assess session 6, we collected the Connections grids that students created.

Pre/post course surveys conducted this past summer show some increase in self-efficacy with regards to mathematics and engineering, with statistically significant increases in students' level of confidence building prototypes, creating circuits, and using breadboards. Students were asked to rate their level of confidence on a scale from 1 (no confidence) to 7 (full confidence). 62 students responded to the pre-course survey and 43 responded to the post-course survey. For all ratings, including 'succeeding in a math class' and 'finding derivatives' the rating went up, indicating that students felt somewhat more confident after the summer program. The biggest increases in confidence were seen in building prototypes, creating circuits, and using breadboards, with pre/post score given in Figure 5; a t-test run for these three rating questions showed that they were statistically significant (p-values $<9x10^{-4}$).

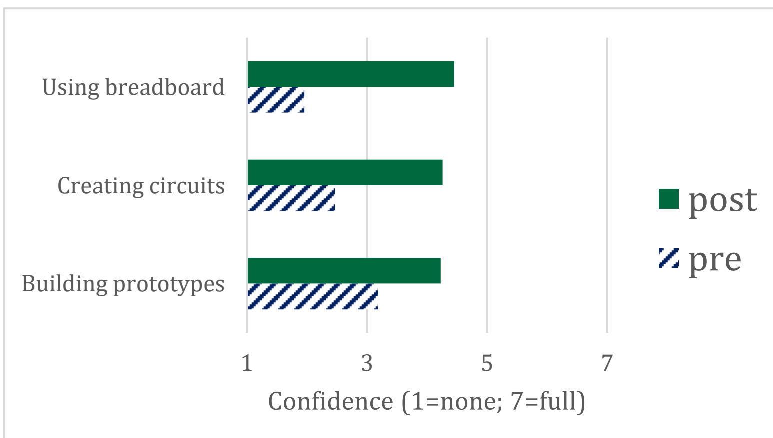

Figure 6. Pre/post-course survey confidence ratings

Conclusions and Future Work

While we were happy to see that students' confidence increased, we'd like to see statistically significant increases in other, more theoretical areas, as well. To that end, we will continue to try to improve the program, with the goal of balancing theory and application. We are tracking the progress and post-program plans of all of the students who participated in the program for a future study.

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