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Work-in-Progress: Introducing First-Generation, Low-income (FGLI) Students to Math and Engineering through a Music-Themed Summer Program

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Petra Bonfert-Taylor received her Ph.D. in Mathematics from Technical University of Berlin (Germany), was a postdoctoral fellow at the University of Michigan and a faculty member in the Mathematics Department at Wesleyan University before accepting her current faculty position at the Thayer School of Engineering at Dartmouth. She was elected a Fellow of the Association for Women in Mathematics in the Class of 2020. Her mathematics research is in geometric function theory and discrete groups; she also has a strong interest in broadening access to high-quality higher education and pedagogical innovations that aid in providing equal opportunities to students from all backgrounds. This passion led her to design and create a seven-MOOC Professional Certificate on C-programming for edX for which her team won the "2019 edX Prize for Exceptional Contributions in Online Teaching and Learning". Previously she designed a MOOC "Analysis of a Complex Kind" on Coursera. Petra is the recipient of the New Hampshire High Tech Council 2018 Tech Teacher of the Year Award, the Binswanger Prize for Excellence in Teaching at Wesleyan University and the Excellence in Teaching Award at Thayer. She recently co-designed and piloted a Foreign Studies Program focussed on green and sustainable engineering in collaboration with the German department at Dartmouth. At Thayer she furthermore leads an AAU funded Teaching Evaluation Project to develop, implement, and document a more effective and holistic teaching evaluation system.

Petra has served as Associate Dean for Diversity and Inclusion at Thayer since 2020. In this role she plans, leads and oversees diversity and inclusion efforts at Thayer and in coordination with other organizations internal and external to Dartmouth. Thayer was recently recognized with the ASEE Silver Diversity Award for our progress in increasing diversity and inclusion of our program.

Background

Every student admitted to Dartmouth who wishes to, is capable of becoming an engineer. Some students who matriculate with an interest in engineering ultimately choose not to major in engineering for good reasons, such as discovering that another major better aligns with their deeper interests, but far too many leave engineering because of gatekeeper courses. Rather than allowing students to explore engineering, the gatekeeper mathematics courses discourage students from continuing to engineering; and the lower students' math placement, the longer they must wait to experience engineering, as they slog through courses taught by and for mathematicians.

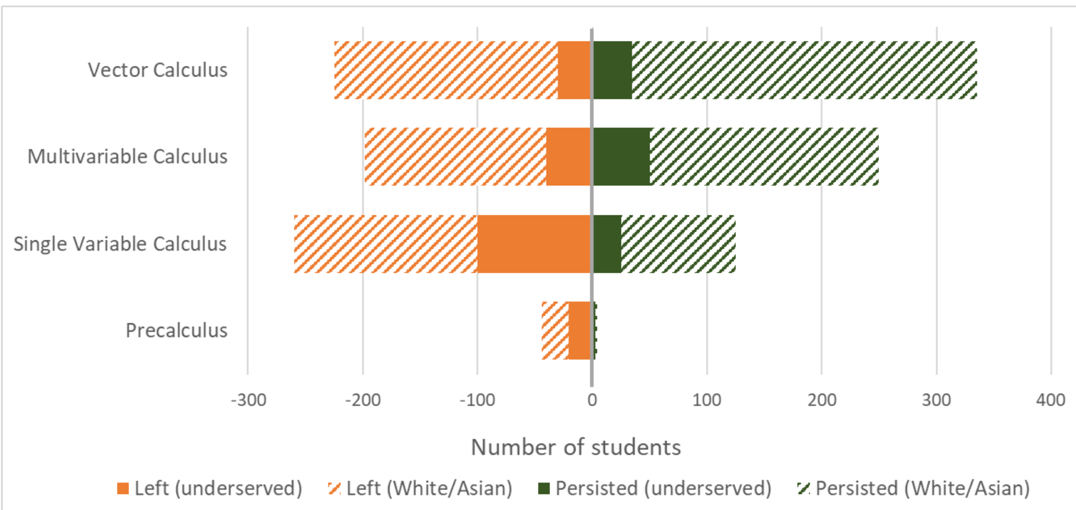

Figure 1. Number of students who left versus persisted in the engineering major, by math placement (cumulative data from Dartmouth graduating classes of 2014 through 2023)

Figure 1 paints a dire picture around these inequities: Students at Dartmouth with an engineering interest who placed into Precalculus were almost never retained in engineering (only ~5% of the students interested in engineering who started in Precalculus ended up majoring in engineering), and the majority (68%) of those who placed into Single Variable Calculus also left engineering. While retention increases to 56% and 59%, respectively, for students who placed into Multivariable and Vector Calculus, there are still many students leaving at this point. Dartmouth engaged in an extensive self-study in 2022 to better understand how aspects of the STEM ecosystem attract, retain, or deter students from historically underserved groups from pursuing STEM courses, majors, and career paths in these fields. The following main issues related to Dartmouth STEM courses were identified (Char and Jewiss, 2022):

- Courses are too theoretical, with little context or real-world application;
- The learning environment is competitive rather than supportive; and
- Preparation among students, particularly in math and science, varies widely.

Quotes from students interviewed for the study (Char and Jewiss, 2022) illustrate these issues:

- “My problem with the STEM departments at Dartmouth is there’s really not a lot of applications, which is what I wanted to find. The math is really theory-based.”
- “You're really outmatched, and not because you’re not smart, but because you just didn’t get the same opportunities.”
- “They [math classes] act as weeder classes.”
- “It’s really challenging, especially in a ten-week term. You get smacked in the face and there’s not enough time to recover.”

Research Questions

Our main research questions are as follows:

- Does students’ self-efficacy in mathematics and engineering increase when mathematical and engineering concepts are introduced and surveyed in a hands-on fashion before students take more theoretical courses?
- Are we better able to retain FGLI students in engineering if they are introduced to mathematical concepts through engineering applications during the summer before their first term?

Program Description

First-generation, low-income (FGLI) students admitted to xxx were invited to participate in a 3-week long summer program aimed at helping them build a cohort, develop a support network, sample academic classes, determine where to go for help, and explore different possible majors. 81 FGLI students participated in the program in 2024, which included 3 intensive mini-courses during the 3-week summer program: a STEM course, a writing course, and a study-skills course. The authors developed and taught the STEM course, which was revised in 2024 to incorporate mathematics, with the goal of putting mathematics into context and hopefully retaining more students.

While there were no grades given for the mini-course, students were asked to submit work both before and after class as a way to get them used to college courses and hold them accountable for the material. 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) and to provide context to the concepts, music was used as a thread for the program. Contextualized courses have been found to improve student confidence and learning (Govindasamy et al., 2018) and tackling engineering design problems has been shown to increase engineering identity and persistence (Gray et al., 2021; Morelock, 2017). Through the STEM course students:

1. Used mathematics to solve engineering and physics related problems;
2. Built and tuned a thumb piano;
2. Used breadboards to create an electric circuit and an electronic piano;
3. Reflected on their own learning.

Some of the materials for the FYSEP program were adapted from a highly successful *Mathematical Concepts in Engineering* course that was created and taught by one of the authors. ALL students who took *Mathematical Concepts in Engineering* in 2018 and who came to xxx with an interest in engineering have been retained in the major. The emphasis in both *Mathematical Concepts in Engineering* and the FYSEP program was on engineering problem-solving and hands-on activities rather than on mathematical derivations and theory. The Common Vision Project (Saxe and Brady, 2015), a joint effort between leaders from five professional associations in the mathematical sciences – AMATYC, AMS, ASA, MAA, and SIAM – collectively considered undergraduate mathematics curricula and ways to improve education in the mathematical sciences back in 2015. The report called on the mathematics community to update curricula with input from representatives in partner disciplines, scale up the use of evidence-based pedagogical methods, find ways to remove barriers facing students at critical transition points and establish stronger connections with other disciplines. It called on instructors to employ a broad range of examples and applications to motivate and illustrate the material, promote awareness of connections to other subjects, and introduce contemporary topics and applications. The authors used the principles outlined in the Common Vision project to design the STEM curriculum for the FYSEP program.

All 81 FGLI students in the FYSEP program participated in the STEM mini-course, which consisted of 3 two-hour class sessions each week. During the first week, which was led by a Computer Science faculty member, the students were introduced to Python and did some coding. Weeks 2 and 3 focused on engineering and mathematics and were led by the authors, both faculty members in engineering, one trained as a mathematician and the other as an engineer. Each of the six engineering mathematics sessions led by the authors are described in Table 1.

Table 1. FYSEP STEM Class Sessions

Session	**Pre-Class Activity**	**In-Class Activity**	**Post-Class Activity**
1 - Intro to Derivative	Introductory Video including Rolling Ball video	Rolling Ball data collection; mini-lecture on derivatives; small group work	Derivatives practice problems and processing of rolling ball data
2 - Derivatives	Use limit definition to find derivatives	Determine and apply shortcuts for finding derivatives in small groups	Derivatives practice
3 - Breadboard	Introductory breadboarding video	Intro to electric circuits mini-lecture; derivatives in electric circuits, breadboarding in small groups	Circuits questions
4 - Circuits	Introduction to circuits video	Build an electronic piano	Circuits questions and derivatives practice
5 - Mechanical Engineering	Engineering reflections	Design and build kalimbas (thumb pianos); develop relationships between beams and frequency	Engineering and derivatives practice
6 - Connections	Connections activity	Mini-lecture to connect music, math, and engineering	Reflections and post-course survey

As shown in Table 1, each class session included both pre- and post-class activities and most class sessions involved group-based activities. Students worked in groups of 4-5 around tables. Four teaching fellows, sophomore students who were hired to help with the program, were available to distribute supplies and help answer questions in and out of class. The electronic pianos and kalimbas that students built are shown in Figure 2. Kalimbas were laser-etched beforehand and students were given a set of tines (steel 'beams') and support pieces that they then had to assemble and tune by adjusting the length of the tines. Electronic pianos involved resistors, buttons, a 555 timer, 9-volt battery, piezo buzzer, and wires that students assembled to create a full octave of notes. Each student assembled their own kalimba and electronic piano that they were able to keep.

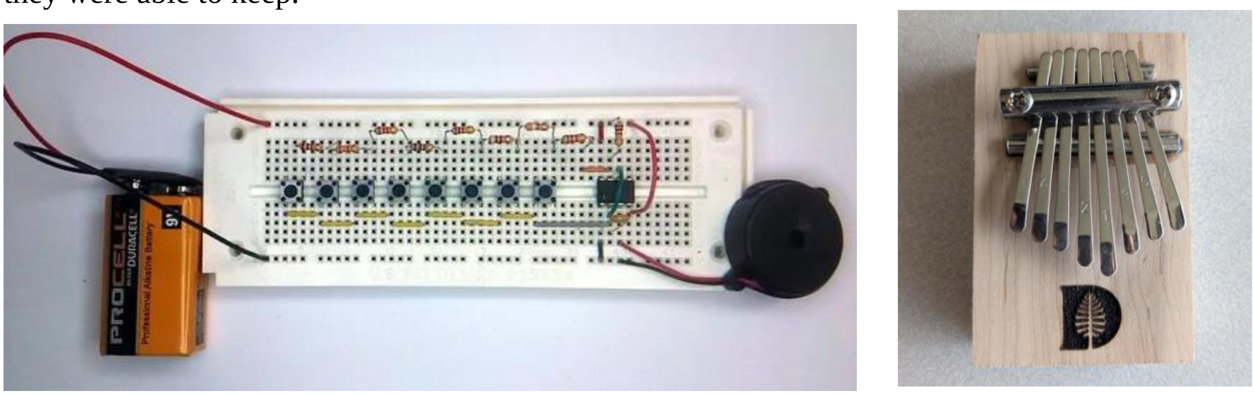

Figure 2. Electronic Piano (https://www.instructables.com/Simple-Electronic-Piano/) and Kalimba

The NYT Connections game (https://www.nytimes.com/games/connections) was used as an engaging way to frame the connections between engineering, music, and mathematics. Author May developed the Connections matrix shown in Figure 3 and used it to discuss ways that engineering, music, and mathematics intersected. Students were encouraged to develop their own, personal connections as well.

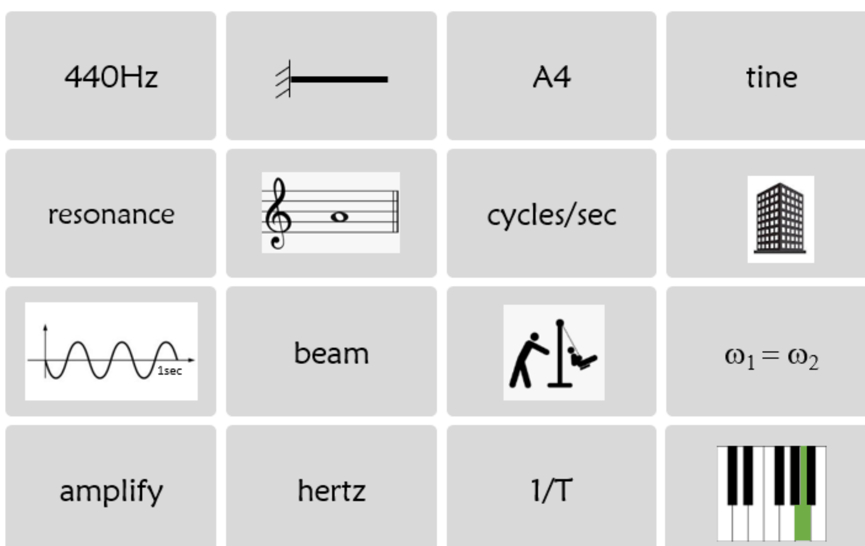

Figure 3. Connections matrix - music, engineering, & mathematics

Outcomes and Feedback

Overall, the authors were happy with the curriculum, which had been adjusted to include mathematics and hopefully served as a better introduction to engineering. In previous years, students had focused on building only, with no analysis nor mathematics. The inclusion of mathematics and analysis seemed more representative of engineering as a profession. Despite not being graded on their work, ~80% of students completed the pre- and post-class assignments. And attendance was high, with only a few students missing during each class period. In addition, all students successfully built a kalimba and an electronic piano.

Students were surveyed prior to and after the mini-course to get feedback on their interests, background, and confidence. When asked to list the major(s) that they were considering, 44 of the 81 students (~54%) listed a STEM major, and 14 students listed engineering, specifically. On both the pre- and post-course surveys, students were asked to rank their confidence on different activities from breadboarding to succeeding in an engineering course using a scale from 1 (no confidence) to 7 (full confidence). Pre/post responses for several of the questions asked are listed in Table 2. While in all cases, the post-survey confidence levels increased, only confidence in Creating Circuits and Using a Breadboard were statistically significant based on a t-test. This is not too surprising given that many of the students in the program had never seen a breadboard nor created a circuit prior to the mini-course.

Table 2. Pre- and Post-Course Confidence levels

Rate your level of confidence…:	Pre-course Average*	Post-course Average*	p-value
Building prototypes	3.79	4.50	0.17
Creating circuits	3.21	4.36	0.03
Using a breadboard	2.64	4.54	0.0004
Finding derivatives	4.50	5.14	0.17
Succeeding in an engineering course	3.79	3.93	0.43

*on a scale from 1 (no confidence) to 7 (full confidence)

Students were also asked to list 3 words they would use to describe engineering; a word cloud depicting their pre- and post-course survey responses are given in Figures 4 and 5. One of the main things that emerged was that students much more strongly associated 'Math' with engineering, possibly more strongly than we had hoped but maybe to be expected given that the first 2 class sessions were dedicated to derivatives and mathematics.

Figure 4. Pre-course survey word cloud (created using worditout.com)

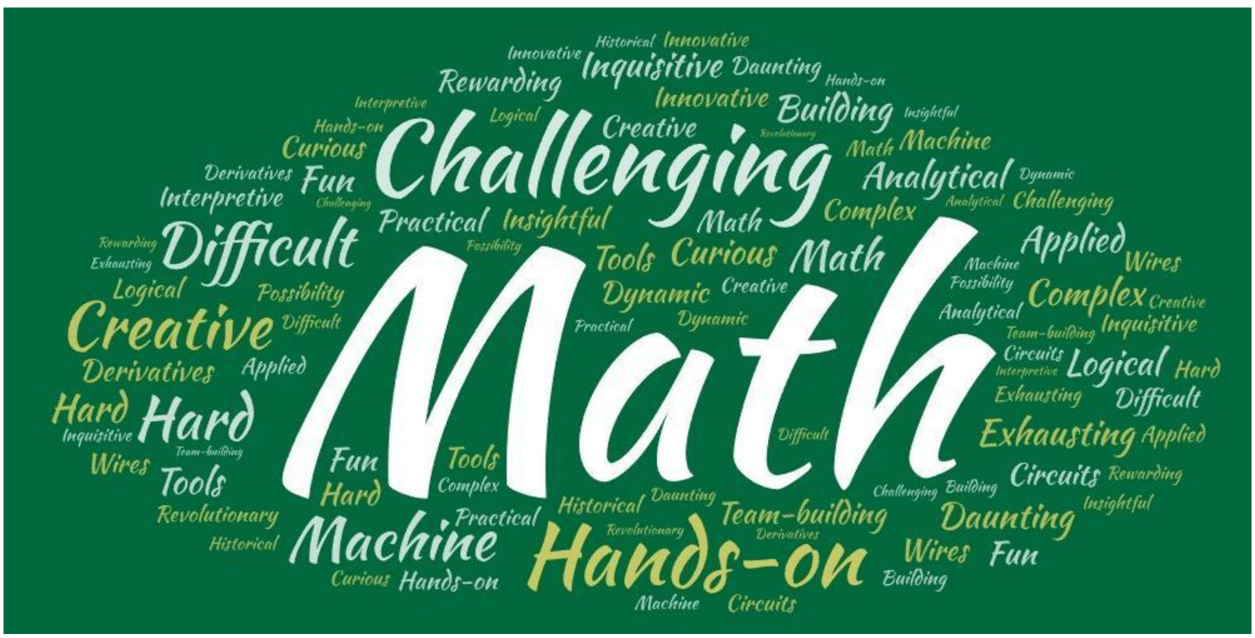

Figure 5. Post-course survey word cloud (created using worditout.com)

Of the 81 students in the program, 41 took a STEM course in the fall of 2024, the fall right after the summer program was offered, so most of the students who had indicated they were considering a STEM major took a STEM class in their first term. Most students took a math or computer science course their first term but a few took a biology or physics course. Of those who took a STEM course in their first term, 5 ended up withdrawing from the course (all who withdrew, withdrew from a math course) and 1 received an incomplete (also in a math course). 38 students are enrolled in a STEM course in the winter term (winter 2025), their second term on campus. Of those students who withdrew from a mathematics course, only 1 has re-enrolled for the winter. We will continue to track the progress of the 2024 FYSEP cohort (and future cohorts) through their academic career.

One of the main challenges was the widely varied background of the students, especially with respect to mathematics preparation. This emerged in the post-course survey comments with several students suggesting that there should be smaller sections based on mathematics background and interest. In addition, some students commented that the mathematics that was presented was too simple, while others commented that it was much too complicated.

Future Directions

While it might be ideal to offer separate, smaller class sessions based on mathematics background, we are not interested in 'tracking' students and want to expose all students to engineering and mathematics. In the future, we plan to better integrate mathematics and engineering, following a just-in-time rather than a just-in-case model. In addition, we'd like to incorporate more design and customization options into the building projects. Thus, rather than having the first 2 class sessions focused solely on mathematics and derivatives, we'll introduce the projects - kalimbas and electronic pianos - earlier and use mathematics as needed to help design and tune them. We will use and apply mathematics rather than simply introduce mathematics. That said, we may still include a few mathematics practice problems, maybe at different levels of difficulty, to help students build confidence. We plan to continue to track students' progress through their academic careers.

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