Board 51: Mathematical Maturity for Engineering Students

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Mathematical Maturity for Engineering Students: NSF project summary

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Abstract

Progress through standard mathematics coursework represents a major barrier to engineering student graduation rates. Long prerequisite chains of mathematics courses have high failure rates, and must be passed to enter engineering coursework. This project aimed to investigate the mathematical expectations of engineering faculty, particularly the ambiguous quality of "mathematical maturity" seen in some engineering-mathematics education research during interviews or workshops. This research aims to create a better understanding of how engineering faculty perceive the mathematical needs of their students.

Interviews with thirty four engineering faculty members at seven institutions revealed common themes across disciplines and institution types. Engineering faculty members stressed the importance of students' ability to apply mathematics to the physical domain. Engineering faculty stressed the need for students to be able to flexibly represent physical entities in a variety of symbolic and graphical forms. They claimed that the ubiquity of computers changes where students mathematical training should focus its emphasis.

The course artifact analysis uncovered substantial mismatch between the mathematics that is taught in calculus courses and how that mathematics is called upon in introductory core engineering courses. Only 8% of homework problems in engineering statics and 20% in circuits used calculus of any kind. What calculus did get used on engineering homework assignments was usually the simplest examples such as polynomials and exponentials.

One round of survey data has been collected, investigating student beliefs about mathematics. This first round used two existing instruments from the literature to probe student beliefs about how relevant mathematics was to their engineering studies. Initial results show moderate beliefs in the relevance of mathematics by sophomore engineering students.

Introduction

Engineering departments are becoming increasingly concerned about retention and graduation rates as industry in the United States demands more engineering graduates to meet expected engineering job growth in coming decades [1]. However, since many students drop out of engineering, too few engineering students graduate to join industry [2]. More specifically, many students drop out of engineering not because they failed an engineering course, but because they failed a mathematics course [3–5]. Some programs blame mathematics courses for as many as a third of their dropouts [2, 6] . Most engineering programs require a standard “calculus sequence” of Calculus I, Calculus II, Calculus III, Linear Algebra, and Differential Equations. Students must pass prerequisite mathematics courses from the calculus sequence to continue into core engineering coursework [7–9] . The strictness of this prerequisite chain can particularly hamper students who are already disadvantaged due to disability or lack of access to high school calculus [10]. Students who do not start calculus-ready or fail a course in the calculus sequence may struggle to complete an engineering degree before financial aid runs out.

Because the calculus sequence has such a strong impact on engineering graduation, engineering departments are increasingly scrutinizing whether these high-failure courses are worth the investment. Engineering departments’ dissatisfaction with the outcomes of calculus [11] has been used to justify drastic curricular change, such as that pursued by the Wright State program [12]. At Wright State, all engineering students take a special engineering mathematics course their first semester, which teaches all mathematics in the context of engineering problems and covers different topics from a typical first-semester calculus course. At other institutions like University of Louisville, the College of Engineering teaches all of the calculus sequence with its own faculty outside of a mathematics department. While it is not clear that the Mathematics Departments were actually at fault for poor student outcomes, the engineering faculty at these institutions clearly believed that to be the case and acted accordingly. Many hold the belief that engineering mathematics should be taught by engineers [13]. Having a better understanding of the mathematical outcomes expected by engineering faculty may help mathematics departments avoid these drastic options.

This NSF project explored the question of “what mathematics do engineering students need” from a variety of angles and methods. I used a combination of interviews with engineering faculty members, analysis of course artifacts, and surveys of engineering students to explore the issue with a mixture of methods and to attain a variety of perspectives.

Methods

Research questions:

1. How do engineering faculty define ‘mathematical maturity’ for engineering students?
2. How much of the mathematics learned in calculus is applied in core engineering coursework?
3. How relevant do sophomore engineering students believe their mathematics training is?

To answer research question 1, I interviewed 34 engineering faculty in 11 disciplines from 7 institutions of higher learning. Most (27) of these faculty came from a single large, research intensive institution, with the remaining 7 distributed over a variety of institution types. I used a qualitative thematic analysis approach to get rich descriptions of what engineering faculty believed to be important in their students mathematical education. To answer research question 2, I analyzed the mathematics needed to complete homework assignments in two core engineering courses, circuits and statics using the mathematics-in-use technique [14]. To answer research question 3, I surveyed engineering students about their beliefs regarding the relevance of their mathematics coursework to their engineering studies. The survey instrument was taken from an existing survey of engineering student beliefs [15]. This project was carried out in a large, elite, American, research-intensive university with a student population of about 44,000 students.

Results

0.1 Faculty Interviews

Preliminary analysis of the faculty interviews has revealed 9 components of faculty's definitions of mathematical maturity for engineering: 1) Fluent algebra skills, 2) Effortless manipulations of mathematical symbols, 3) Translating real world problems into equations, 4) Ability to use computational tools to solve mathematical problems, 5) Fluency with notation, 6) Willingness to explore multiple solution approaches, 7) Perceive mathematics as the language of technical communication, 8) Able to interpret the real world implications of mathematical expressions, and 9) Confidence when using mathematics.

0.2 Homework Analysis

The skills from Calculus that are applied in Statics are low in both abundance and diversity. Only 8% of problems in statics apply calculus in any way, and the portion of calculus that is applied is very limited. Only a tiny fraction of the content taught in calculus is used in Statics. The situation in Circuits is similar. Only 20% of problems in Circuits use calculus, but the diversity of concepts that are called upon in Circuits is moderately diverse. Integration, differentiation, and limits all occur in at least one lesson as a real tool. In both courses, robust applied algebra skills are the primary mathematical tools needed to succeed.

In both courses, most functions encountered are relatively simple, such as polynomials and exponential functions. The calculus that does occur usually hews close to the most basic functions. Many topics in calculus find little to no application in the engineering courses that list it as a prerequisite. This presents a problem for the curriculum, since students are very likely to forget content that is not practiced, meaning that the material may be forgotten before later courses that use more calculus such as Signal Processing or Dynamics.

0.3 Student Survey

I present some initial results of the student survey. Unfortunately, the small sample size precludes exploratory factor analysis. However, basic statistics and comparison to previous work can be presented. Overall, students have moderate views of how relevant their mathematics coursework is to their engineering studies.

Overall, students had moderate to slightly positive views of the relevance of mathematics to engineering. This result appears much like a dampened version of the results from Flegg et al.'s work. There is a majority of students that believe math is relevant, but this majority is not as overwhelmingly large as in Flegg et al.'s work [15].

flegg_chart.png

Figure 1: Student survey responses to Likert scale items copied from Flegg et al.(after inconsistent items removed).

0.4 Limitations

These studies have many limitations, outlined below:

- Studies were conducted at a large, elite, research-intensive American institution. Such an institution will not be representative, but can be considered a sort of upper bound on the needed mathematics at a more typical institution.
- Interviews with faculty may not be completely reliable, they may overstate the mathematics they need. However, this limitation is mitigated by the analysis of course artifacts.
- Opinions of faculty are only opinions, they may not reflect the true needs of their students.
- The analysis of course artifacts only examined two engineering courses, and is far from comprehensive.
- The response rate in the student opinion survey was poor (about10%). This decreases confidence in those results.
- Engineering mathematics exists in a complicated ecosystem with many stakeholders, such as transfer schools, national testing, and high schools. Results from this work should be interpreted cautiously.

Discussion

0.5 Future Steps

Future work has a number of promising ways to extend this work. The small number of courses studied for their content could be expanded, and would form much stronger evidence if supplemented with more courses from the engineering core, such as thermodynamics, mechanics of materials, and introductory physics. The actual success of transfer of mathematical knowledge to engineering coursework was not investigated, future work could investigate how much knowledge is successfully transferred. Finally, this work does not investigate or suggest any particular interventions to improve the top level goals, future work could investigate modeling instruction, integrated curricula, or similar intervention approaches.

0.6 Conclusion

Mathematics is and will continue to be a very important tool for engineering and engineering students. However, there are substantial mismatches between the mathematics that is taught and the needs and desires of engineering students. Engineering faculty find many applied mathematics skills wanting in their students. The timing of mathematical preparation and application for engineering students is mismatched, leading to potential to forget what they have learned. Engineering sophomores have only moderately positive views of how relevant mathematics is to their education. This describes the situation as it is. However, earnest collaboration between engineering and mathematics educators could potentially disrupt this pattern.

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