Mind the Gap: A preliminary Investigation into the Gaps Between Faculty and Student Expectations in Engineering Mathematics Instruction

Ms. Sasha Gollish, University of Toronto

Sasha is a PhD Candidate in Engineering Education in the University of Toronto's Faculty of Applied Science and Engineering Institute for Studies in Transdisciplinary Engineering Education and Practice focusing on the connection of mathematics to engineering. She is also a registered and practicing professional engineer.

Prof. Bryan Karney, University of Toronto

Bryan W. Karney graduated from UBC in Bio-Resource Engineering in 1980 and completed his Ph.D. in Civil Engineering, also for UBC, in 1984. He is currently a professor of Civil Engineering and the Associate Dean of Cross Disciplinary Programs at the University of Toronto. He is also the principal of HydraTek & Associates Inc, a hydraulic transient analysis specialty firm. Dr. Karney is the senior hydraulic transient specialist in the company with almost 30 years of direct experience in providing hydraulic and hydraulic transient consulting services on a wide range of fluid pipe systems, including water, wastewater, oil, gas, and jet fuel. Bryan has spoken and written widely on subjects related to water resource systems, energy issues, hydrology, climate change, engineering education and ethics. He was Associate Editor for the ASCE's Journal of Hydraulic Engineering from 1993 to 2005. He has written or co-written numerous journal papers and articles, including the book titled "Comprehensive Water Distribution Systems Analysis Handbooks for Engineers and Planners, published by MWH Soft. Bryan has won a number of teaching awards and recognitions including being a finalist in the TVO's best lecturer competition and received the American Water Works Association's (AWWA) award for the Best Engineering and Construction Publication Article for 2008. Dr. Karney was awarded the Northrop Frye award for excellence in teaching and research in 2009.

A Preliminary Investigation into Mathematics for Undergraduate Engineering Education to Improve Student Competence in Important Mathematic Skills

Key Words: mathematics, mathematics instruction, pedagogy, instructional design, curriculum design

Introduction

Engineers must have an understanding of mathematics. It is impossible to receive an undergraduate engineering degree, and later a professional engineering license, without mathematics instruction at a post-secondary level. Yet, undergraduate engineering students frequently struggle with mathematics. The connection between mathematics and engineering, that is the ability for students to transfer their knowledge from mathematics courses to other engineering courses, has been documented as difficult for students (Holmegaard, Madsen, & Ulriksen, 2016; Basitere & Ivala, 2015; Klingbeil, Rattan, Raymer, Reynolds, & Mercer, 2009; Willcox & Bounova, 2004; Harper, Baker, & Grzybowski, 2013). Addressing how to improve student's performance in mathematics has bounced back and forth between a traditionalist back-to-basics focus on teaching facts and knowledge, and a reformist focus on problem solving and process (Schoenfeld, 2004)

Through a mixed-methods study over the course of the 2017-2018 academic year in the Faculty of Applied Science and Engineering (FASE) at the University of Toronto, this study sought to answer the following questions: To what extent does mathematics play an important role in undergraduate engineering education? Do the FASE instructors believe that undergraduate engineering students can competently apply mathematic principles in engineering classes? And finally, how should mathematics be taught as it relates to undergraduate engineering?

The findings from this mixed-method study suggest the respondents from FASE believe that mathematics does play an important role in engineering, with calculus being the most important skill, and both linear algebra and statistics also playing a significant role. In addition, the respondents believe that students' competence ranks lower than the importance of the general and specific mathematic skills. Finally, faculty were unsure if mathematics should be taught toward the abstract or toward the applied, but in general, believe that the teaching of mathematics to undergraduate engineering students should have examples that are tied to engineering. While both categories of mathematics, abstract and applied, are important in undergraduate engineering, a third paradigm for teaching is offered, an engineering mathematics lens. Engineering mathematics could combine the necessity for an understanding in both abstract and applied mathematics but relates examples to all facets of engineering. An engineering mathematics lens could offer part of a solution to helping to close the gap as it relates to these essential mathematics skills needed for instruction in engineering education.

Methods

A mixed-method study was used to assess the connection between mathematics and engineering at FASE. An explanatory sequential method was selected to combine the use of both qualitative and quantitative data in a meaningful way to capture the mathematics teaching and learning environment at FASE. First a survey was developed and administered to FASE faculty in the 2017 fall term. From the results of the survey a set of interview questions were developed. Following this, semi-structured interviews were conducted amongst interested faculty in the 2018 winter term. A post-positivist, pragmatic lens was used to evaluate the data that was collected in both the faculty surveys and the semi-structured interviews.

Three research questions were developed to measure the connection of mathematics to engineering at FASE. The research questions included:

- To what extent does mathematics play an important role in undergraduate engineering education?
- Do FASE instructors believe that undergraduate engineering students can competently apply mathematic principles in engineering classes?
- How should mathematics be taught as it relates to undergraduate engineering?

Further sub-questions were developed to help probe these research questions, but these have been excluded in this report for brevity.

FASE faculty were asked to rate together the importance of the stated skill and their perception of student competence in this same skill. Two questions, that spoke to the various general and specific skills, were posed using a five-point Likert scale asking respondents to rate the various mathematics skills from 1-Not Very True to 5-Very True. These questions were developed using a study that was originally done at The Ohio State University but were adapted to fit the requirements for this project (Harper, Baker, & Grzybowski, 2013). The two key questions posed in the survey are these:

- How important is it for students from the University of Toronto undergraduate engineering program to be able to competently apply mathematics concepts from each of these areas listed?
- How competent (i.e., what level of competence to you perceive) is the average student from the University of Toronto undergraduate engineering program in the following areas?

The survey was administered through the Dean's office to all faculty; an introductory email and a follow up reminder were sent over a period of six weeks. The data was collected using an online survey tool. A Portable Document File (PDF) and fillable Microsoft Word Document were also included in the email. Following a preliminary analysis of the data collected from the survey semi-structured interview questions were written.

Results

From the mixed method study the following results are discussed. There were 261 faculty for the 2017-18 academic year spread across the seven departments at FASE. The response rate was 24%. Of the faculty that responded to the survey, 56% were professors, 31% were associated professors, 11% were assistant professors, and 3% were professor emeritus. The percentage of respondents by department is shown in Table 1.

Department	Responses
Department of Chemical Engineering and Applied Chemistry	22.2%
Civil and Mineral Engineering,	15.9%
Materials Science and Engineering	1.6%
Mechanical and Industrial Engineering	20.6%
The Division of Engineering Sciences	1.6%
The Edward S. Rogers Sr. Department of Electrical and Computer Engineering	30.2%
University of Toronto Institute of Aerospace Studies	4.8%
The Institute of Biomaterials and Biomedical Engineering	0.00%
The Institute for Studies in Transdisciplinary Engineering Education and Practice	3.2%

Table 1: FASE Respondents Department Representation

The survey asked respondents about the importance of general and specific skills required for undergraduate engineering and how competent undergraduate students are in these same skills. The results are summarized below in Table 1 and Table 3. The standard deviation is shown in brackets beside the mean value.

Topic	Average Importance	Average Competence
Calculus	4.20 (1.08)	3.20 (0.96)
Linear algebra	3.82 (1.18)	2.59 (1.04)
Analysis of nonlinear phenomena	3.10 (1.08)	1.69 (1.04)
Ordinary differential equations	3.75 (1.27)	2.59 (1.18)
Partial differential equations	3.23 (1.27)	1.92 (1.15)
Complex variables/functions	2.97 (1.25)	1.78 (1.11)
Numerical simulations	3.74 (1.26)	2.33 (1.12)
The use of vectors to represent physical quantities	3.70 (1.26)	2.46 (1.17)
Discrete Math	3.02 (1.20)	1.65 (1.13)
Numerical Solutions	3.61 (1.14)	2.44 (1.05)
Statistics	3.70 (1.16)	2.20 (1.02)

Table 2: Summary of Faculty Ratings of Importance of and Students' Competence with these 11 Mathematical Topics. Ratings are on a 5-point scale. Numbers in parentheses are standard deviations.

Specific Mathematical Skills	Average Importance	Average Competence
Evaluating solutions/checking work	4.49 (0.80)	3.30 (0.79)
Being familiar with units and dimensions	4.56 (0.84)	3.42 (0.95)
Knowing how to create and interpret graphs	4.51 (0.82)	3.12 (1.00)
Performing algebraic manipulations	4.05 (1.14)	3.12 (0.98)
Knowing how to convey & interpret engineering relationships through mathematical expressions	4.32 (0.99)	2.61 (0.98)
Using parameters/symbols, rather than numerical values, in analysis	4.27 (0.93)	3.12 (1.05)
Interpreting the role of parameters in mathematical expressions	4.17 (0.99)	2.72 (1.00)
Formulating mathematical models	4.14 (1.02)	2.26 (1.04)
Being familiar with estimation/knowledge of magnitude scales	4.39 (0.81)	2.84 (0.99)
Knowing when to differentiate or integrate	4.12 (1.18)	2.75 (1.06)
Working with multivariable problems	3.98 (1.04)	2.25 (1.22)
Creating algorithms	3.64 (0.98)	2.18 (1.04)

Table 3: Summary of Faculty Ratings of Importance of and Students' Competence with these 12 Specific Mathematic Skills. Ratings are on a 5-point scale. Numbers in parentheses are standard deviations.

The results from these four questions, two for importance and two for competence, as they relate to the general and specific mathematics skills necessary for student success in undergraduate engineering as suggested by the respondents, imply that calculus is the most important general skill and being familiar with units and dimensions as the most important specific skill. Regardless of listed skill there is a gap between the rated importance of that skill for student success and student competence in that same skill by the respondents from the survey.

The final question asked respondents to share how they believed mathematics should be taught to engineering students. Using a 5-point Likert scale the respondents were asked to answer questions regarding mathematics teaching; should mathematics for engineering students be taught through a category of abstract, applied or engineering mathematics? Figure 1 shows the results of the responses.

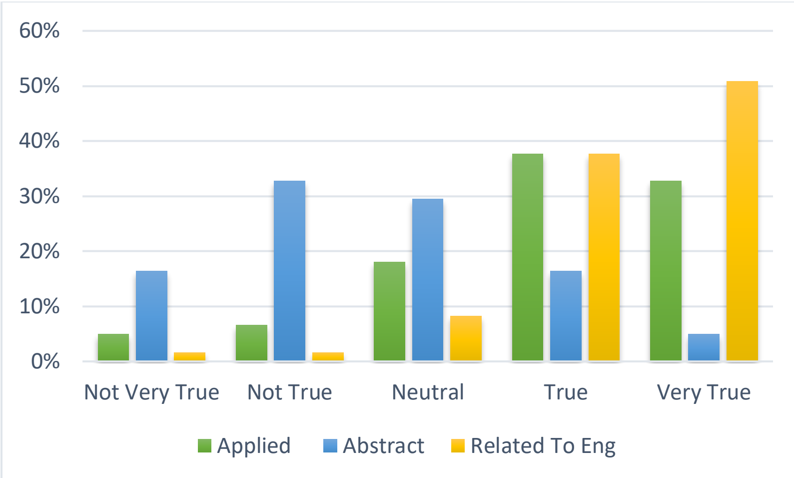

Figure 1: Categories to Teach Undergraduate Engineering Mathematics: A Comparison of Abstract, Applied, and Related to Engineering.

While respondents were unsure if undergraduate engineering should be taught through an abstract lens, they generally agreed that it should be taught through an applied lens, and further they agree strongly that mathematics should be taught as it relates to engineering.

Conclusion and Next Steps

There are two themes that arose from the data collection that warranted further discussion and exploration. First, there is a notable gap between the identified important mathematics skills for student success in undergraduate engineering and the students' competence in these very same skills. This is demonstrated in the above tables for both the general and specific mathematics skills if one compares the results from importance and competence; in every case importance is rated higher than competence.

Second, the respondents believe that mathematics in undergraduate engineering should be taught through and with engineering examples but were unsure if that should be through the categories of applied or abstract mathematics. It was generally agreed upon that both abstract and applied mathematics are needed to be an engineer.

The next steps include further analysis of the survey data and semi-structured interviews to include deeper discussion of the results.

References

Basitere, M., & Ivala, E. (2015). Problem Based Learning and Authentic Assessment in Digital Pedagogy: Embracing the Role of Collaborative Communities". *The Electronic Journal of e-Learning, 13*(2), 68-83.

Costa, A., & Kallick, B. (2008). *Learning and Leading with Habits of Mind: 16 Essential Characteristics for Success.* Alexandria: Association for Supervision & Curriculum Development.

Harper, K., Baker, G. R., & Grzybowski, D. M. (2013). First Steps in Strengthening the Connections Between Mathematics and Engineering. *PEER.* Atlanta: American Society for Engineering Education.

Holmegaard, H. T., Madsen, L. M., & Ulriksen, L. (2016). Where is the engineering I applied for? A longitudinal study of students' transition into higher education engineering, and their considerations of staying or leaving. *European Journal of Engineering Education, 41*(2), 154-171.

Klingbeil, N., Rattan, K., Raymer, M., Reynolds, D., & Mercer, R. (2009). The Wright State Model for Engineering Mathematics Education: A Nationwide Adoption, Assessment and Evaluation. *PEER: Annual Conference and Exposition* (pp. 14.1265.1 - 14.1265.17). Austen : American Society for Engineering Education.

Schoenfeld, A. H. (2004). The math wars. *Educational Policy*, 253-286.

Willcox, K., & Bounova, G. (2004). Mathematics in Engineering: Identifying, Enhancing and Linking the Implicit Mathematics Curriculum. *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition Copyright* (pp. 9.896.1 - 9.896.13). Salt Lake City: American Society for Engineering Education.