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Work In Progress: Assisting Academically Underprepared Engineering Students in Mathematics

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Dr. Jaskirat Sodhi is interested in first-year engineering curriculum design and recruitment, retention and success of engineering students. He is the coordinator of ENGR101, an application-oriented course for engineering students placed in pre-calculus courses. He has also developed and co-teaches the Fundamentals of Engineering Design course that includes a wide spectra of activities to teach general engineering students the basics of engineering design using a hands-on approach which is also engaging and fun. He is an Institute for Teaching Excellence Fellow and the recipient of NJIT's 2018 Saul K. Fenster Innovation in Engineering Education Award.

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Background

Foundational understanding of mathematics topics is a common prerequisite for several engineering courses. Due to this, mathematics courses form an integral part of the first-year engineering curriculum. Majority of engineering schools use a placement test to determine which math course incoming first-year students are placed in. However, engineering students are often underprepared in several pre-calculus topics. To assist these underprepared students, a significant percentage of first-year students at our midsize STEM University are placed into remedial pre-calculus courses. At our institution, the percentage of first-year students placed into pre-calculus is about 35%, averaged over the past five years. This distribution has only slightly improved over the years despite a significant increase in the average student profile in terms of SAT/ACT scores and high school GPA. Furthermore, a large number of students placed into calculus fail or withdraw from it, automatically leading to additional semester(s). An explanation for this can be that a sizable amount of the incoming first-year students are underprepared in mathematics. Another rationale can be that students find it difficult to establish a connection between mathematics and engineering, thus losing their motivation to do well in their coursework. More often than not, this leads to students switching to non-engineering majors or leaving the university altogether.

To offer mathematics remediation and simultaneously assist students establish a connection with engineering, our institution has been offering an “Engineering 101” introductory course since Fall 2016. The course is based on the nationally-recognized Wright State University (WSU) engineering mathematics education model which has been developed to increase student retention and motivation by provided contextualized-mathematics education. This model has been adopted in 40+ engineering schools nationwide [1-2]. The idea is to teach mathematics to incoming first-year students using an application-oriented, hands-on introductory course. This course provides an overview of relevant topics in engineering analytical methods from core sophomore-level engineering courses, which are reinforced through extensive examples of their use in lab exercises. Topics include algebraic manipulation of engineering equations; use of trigonometry, vectors and complex numbers, sinusoids and harmonic signals, systems of equations and matrices in engineering applications; and basics of differentiation and integration in engineering applications. The WSU model was first implemented in 2004 and has been used successfully since then. At WSU, every department requiring this course saw an increase in first-year retention in 2004-2005, as compared to baseline data averaged over the prior four years. Overall, WSU saw first-year retention increase from 68.0% to 78.3%. In addition to first-year retention, this model has had a significant impact on student performance in calculus at WSU. Of the students ultimately enrolled in calculus I, 89% of those who had formerly taken this course earned a “C” or better, compared to only 60% of those who had not [3].

Similar positive impact has been noted for our Engineering 101 course justifying its continued offering [4-6]. To further improve the course, the presented work focusses on the identification of topics of difficulty and areas of error in enrolled students’ mathematical problem-solving. The purpose of this work is to develop research-based insights for revising the future offerings of the course to better assist the enrolled underprepared students.

Methodology

The study was conducted in a remedial mathematics course offered at a midsized research university in Spring 2020. The 4-credit course meets for 90 minutes of lecture two times a week, and 90 minutes of recitation and 90 minutes of lab meetings once a week. It's a required course for all engineering students taking pre-calculus and are one term behind the expected starting point. The total enrollment of the course was 45 students. The data source for our study included students' solution to homework and exam problems. Specifically, the homework and exam problems focused on solving engineering or physics problems using the application of linear equations. These problems covered different areas of application such as Mechanics, Linear Algebra, Thermodynamics, Electrical Circuits, Kinematics, and Vectors.

We performed a qualitative analysis of homework and exam solutions in a three-step process. First, one researcher performed an initial review of the solutions to familiarize themselves with the data set. In this process, the researcher identified common errors students committed and developed a general list of different error types. Second, the preliminary list of errors from Step 1 were discussed with a second researcher to provide an external check to the data analysis. Third, the list of errors was categorized jointly by the two researchers based on conceptual similarity.

Results

Four key error categories emerged from our data analysis as described in Table 1. Overall, while minor errors attributed to calculation mistakes were found, plotting and variable identification errors were most common in both homework and exam solutions. In case of plotting, in addition to not being able to identify and label crucial points on a plot (e.g. x intercept and y intercepts); students plotted the line representing a physical quantity outside its viable limit. For example, sketching the plot of temperature versus volume on the x and y axis respectively, students were not able to label the absolute zero (x-intercept). Furthermore, students extended the plot line under the x axis which incorrectly represented the volume as negative. This indicates that the students are not able to draw the connection between the mathematical procedure and the physical quantity involved in the given problem. In case of variable identification, students were unable to correctly identify the independent and dependent variables. This was evident in formulating the initial linear equations and/or switching the independent and dependent variables when finding the slope of a linear equation.

Table 1. Description of Error Categories

Category	**Description**
Minor errors	Incorrect steps in computation, calculation mistakes, and missing units.
Variable Identification	Incorrect identification of independent and dependent variables.

Plotting	Incorrect range of Physical Quantity as well as exhibiting a lack of practicality
Equation Identification	Wrong identification of linear or quadratic equation.

Similar patterns of occurrence of error types were noted in homework and exam solutions with few differences. In the homework solutions (Figure 1(a)), ‘plotting’ and ‘variable identification’ errors were similarly predominant, accounting for a total 69% of all errors. Minor Errors accounted for 25% of all errors and Equation Identification errors were the least noted (6%). In exam solutions ((Figure 1(b)), the two most predominant error categories were ‘plotting’ and ‘variable identification’, accounting for 48% and 25% of all errors, respectively. Minor Errors accounted for 27% of all errors and no errors were found for the ‘Equation Identification’ category.

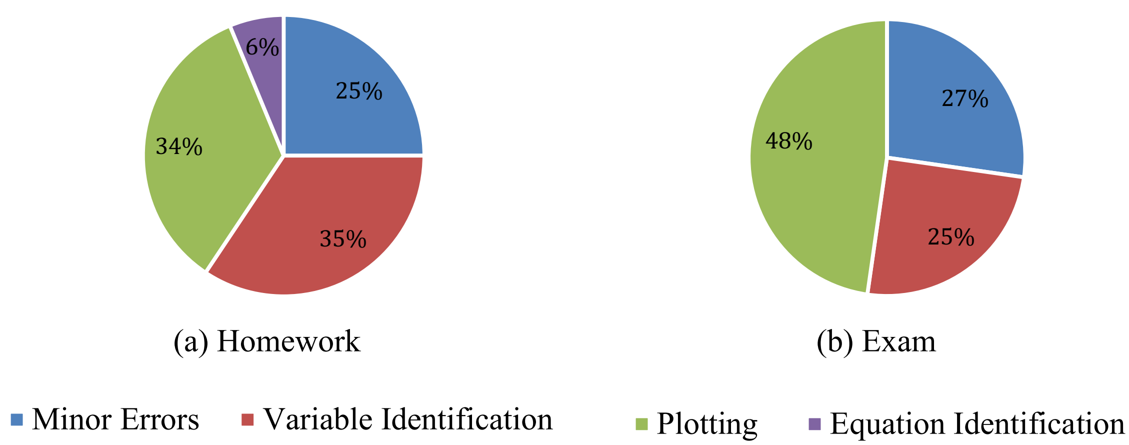

Figure 1. Distribution of Error Categories

Conclusion

This study identifies common areas of error for students enrolled in a remedial mathematics course. The emerging error categories pertinent to the topic of linear equations unpacks areas of conceptual difficulty that underprepared students may encounter. Instruction and curriculum that targets these topics will better assist students in developing the required mathematics proficiency. In our ongoing and future work, we intend to examine other topics of the course to develop a holistic understanding of student learning needs in pre-calculus remedial courses. These findings will inform future revisions of the offered course and subsequent assessment of the revised instruction.

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