Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #48714

The Impact of Prior Knowledge on Students Performance and Help-Seeking Behavior in a Graduate Engineering Math Course

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Julie Spencer finished her Ph.D. in math from the University of Virginia in August of 2014. During graduate school, she developed a deep excitement about teaching math, and was able to spend the last year of her dissertation teaching at Mary Baldwin College (now Mary Baldwin University), a small women's liberal arts school. In Fall of 2015, she started teaching applied math with the School of Engineering and Applied Sciences at the University of Virginia. During her time at the University of Virginia, she has taught ordinary or partial differential equations almost every semester. She has been putting work into refining these classes so that they involve more active learning and critical thinking for students. In 2020-2021, she redesigned ordinary differential equations with two other professors to make it an inquiry-oriented class.

The Impact of Prior Knowledge on Students Performance and Help-Seeking Behavior in a Graduate Engineering Math Course

Engineering Math I is an introductory graduate-level course cross listed between the Applied Math department and the Mechanical Engineering department at the University of Virginia, a large public university. The course covers ordinary differential equations, linear algebra, and partial differential equations. Students enter this course with a wide variety of mathematical knowledge and comfort. Some students have already taken courses that cover most, if not almost all, of the material in the course, and some haven't taken any. For those who have taken previous courses with overlapping content, there is also a wide range of time between the previous courses and Engineering Math I. Moreover, as this is an introductory graduate-level class, students are coming in from a lot of different schools, meaning they all have slightly different training. Finally, the students are a combination of master's students, PhD, students, and remote students, all of whom have very different demands on their time and energy.

Course Structure and Background

Engineering Math I is taught in a flipped manner, where students watch video lectures outside of class and use their time in class to work on problems in a supported environment, and to take (almost) weekly quizzes. The first time I taught the class, in the Spring semester of 2023, I used a traditional lecture format, but I found that students taking the class in person often needed to miss class meetings because of other responsibilities they had as graduate students, and that there was too much content to cover the content in class and to give students supported time to practice problems. Moreover, the course was (and still is) set to having two 75-minute class meetings each week, and that proved to be a long time for students to sit and listen to me talk about the course content. Getting students engaged was an added difficulty. Finally, having two midterm exams posed problems with student preparedness (from not keeping up with the material) and time management on tests. To address these issues, the next time I taught the class, in Fall of 2023, I switched to presenting content through video lectures outside of class and using class time for students to work on low-stakes worksheets one meeting day each week and take weekly quizzes on the other meeting day. This encouraged students to keep up with the material and made sure they had time to practice the work in a supported environment. It also allowed me to give in-depth questions on the quizzes without worrying about students being able to finish them within the allotted time. I kept this structure when I taught the class again in the Fall of 2024.

Study Motivation and Research Question

After teaching this Engineering Math I for a couple of semesters, I started to notice a wide variety of students' comfort and familiarity with the topics in the class and the mathematical content that would be useful to understand coming into the course. There are no official prerequisite classes. The only requirement for students to sign up is graduate standing. Because of this, it is especially important that students have a chance to succeed in the course regardless of whether they've taken a linear algebra or a differential equations class before. The impact of students' prior knowledge and performance in (Wright et al., 2019) and time since prerequisite courses (Wilck et al., 2016), as well as the use of additional material to help bridge any gaps (Watson et al., 2022) has been studied in courses in a number of engineering fields. However, most of this work focuses on undergraduate students rather than graduate students. My research question is:

- How, if at all, does graduate students' performance on a diagnostic assessment relate to subsequent performance on future quizzes and in the course?

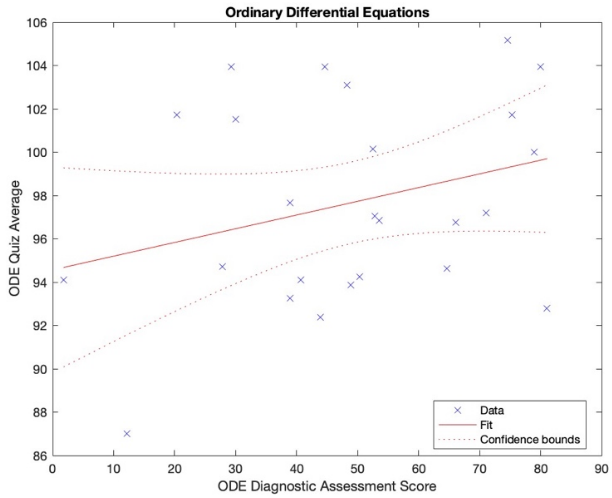
Methods

On the very first day of class, before starting to cover any course content, I administrated a diagnostic assessment covering topics from precalculus, calculus, ordinary differential equations, and linear algebra that would be relevant to the course, and that I would expect students to know when they come in. I asked students not to study for this diagnostic assessment and informed them that not getting the questions correct wouldn't hurt their course grade. Engineering Math I has three major components: ordinary differential equations, linear algebra, and partial differential equations. I mapped each question in the diagnostic assessment to one or more of these topics (some questions related to both ordinary and partial differential equations and were mapped to both subjects). Each student was then assigned a grade from the diagnostic test for each of these three topics. After the semester was over and students had completed their IRB consent forms, I calculated quiz averages for each of these three topics and ran a linear regression test to determine whether a linear relationship exists between diagnostic assessment scores and quiz scores for each topic. I also ran a linear regression test to determine whether there was a linear relationship between course scores and overall diagnostic test scores.

Results

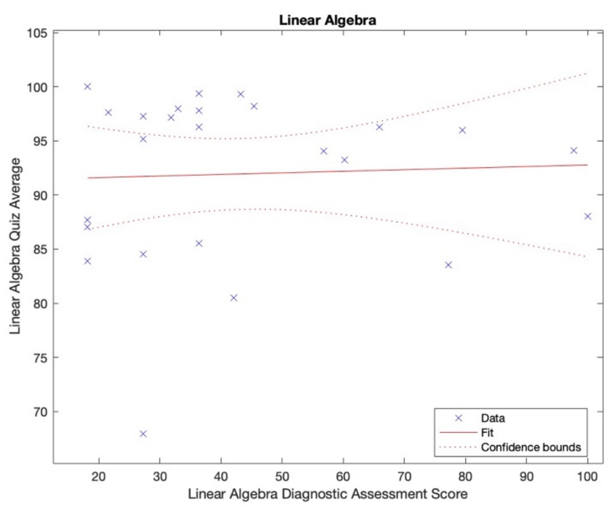
There were 55 students registered for Engineering Math I during the Fall of 2024, and we were able to get IRB consent from 25 of them. Based on results from the students who consented to participate in the study, I ran four tests for significance of regression: one comparing diagnostic test scores for material relating to ordinary differential equations with quiz scores on ordinary differential equations, one comparing diagnostic test scores for material relating to linear algebra with quiz scores on linear algebra, one comparing diagnostic test scores for material relating to partial differential equations with quiz scores on partial differential equations and one comparing overall diagnostic scores with course grades.

A scatterplot for the ordinary differential equations material, including a line of best fit, is given below:



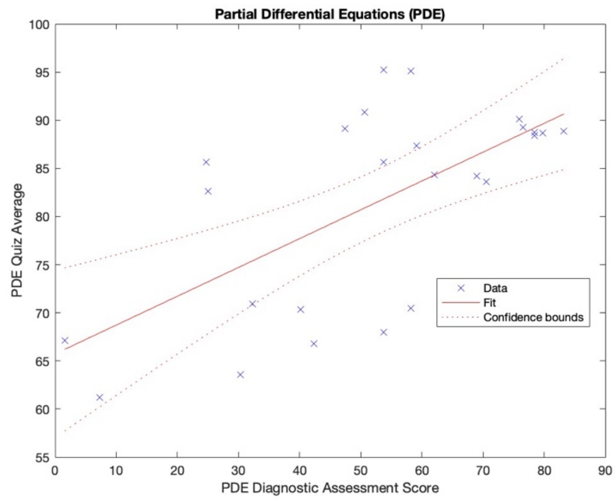
A linear regression established that the diagnostic test score for material relating to ordinary differential equations could not statistically significantly predict the average quiz score for quizzes on ordinary differential equations. I found that $F(1,23)=2.18$, yielding a P-value of 0.15337. Because this is above the standard threshold of 0.05, the linear model predicting quiz scores in ordinary differential equations based on corresponding diagnostic scores lacks utility.

A scatterplot for the linear algebra material, including a line of best fit, is given below:



A linear regression established that the diagnostic test score for material relating to linear algebra could not statistically significantly predict the average quiz score for quizzes on linear algebra. I found that $F(1,23)=0.048$, yielding a P-value of 0.828. Because this is well above the standard threshold of 0.05, the linear model predicting quiz scores in linear algebra based on corresponding diagnostic scores lacks utility.

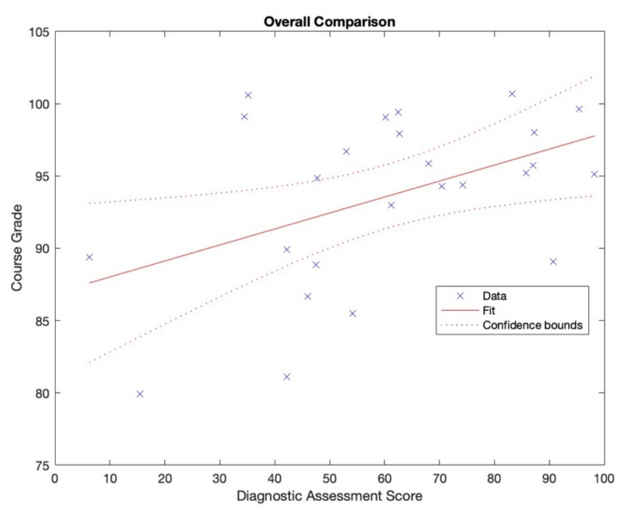
A scatterplot for the PDE material, including a line of best fit, is given below:



A linear regression established that the diagnostic test score for material relating to partial differential equations could statistically significantly predict the average quiz score for quizzes on partial differential equations. I found that F(1,23)=16.5, yielding a P-value of 0.000483, which is well below the standard threshold of 0.05. Using D for the diagnostic test scores relating to partial differential equation and Q for the predicted average quiz score relating to the same topic, the regression equation was:

$$Q = 65.729 + (0.29933)D$$

Finally, a scatterplot for the overall diagnostic assessment score and the course grade, including a line of best fit, is given below:



A linear regression established that the diagnostic test score for material relating to partial differential equations could statistically significantly predict the average quiz score for quizzes on partial differential equations. I found that F(1,23)=6.04, yielding a P-value of 0.0219, which is well below the standard threshold of 0.05. Using T for the overall diagnostic test and G for the predicted course grade, the regression equation was:

$$T = 86.915 + (0.11052)G$$

Limitations
One major limitation is that less than half of students registered for the class consented to be a part of this study. Thus, these results may not accurately represent the class as a whole. Another is that partial differential equations is naturally a more difficult subject in Engineering Math I than the ordinary differential equations and linear algebra that we cover. Finally, partly due to this difference in difficulty, students were given access to more additional optional practice resources for ordinary differential equations and linear algebra than they were for partial differential equations. This disparity might be part of the reason that the partial differential equations scores on the diagnostic test were such a strong predictor for quizzes in partial differential equations.

Conclusion
Despite the limitations, based on the data we do have, performance on the diagnostic test did not have a statistically significant correlation with quiz grades in ordinary differential equations or linear algebra. This can be interpreted to mean that students' prior knowledge in these subjects does not have a significant impact on their corresponding course grade for these subjects. However, there was a statistically significant correlation between diagnostic test scores and quiz grades in partial differential equations, and in the overall course grade. This indicates that there is room for improvement in the equity of the partial differential equations portion of the class. Moreover, it seems that the impact on the partial differential equations portion of the class is large enough to impact course grades overall. I'm happy to report that overall, grades in this course were pretty high, with nobody who participated in the study getting a course grade below a B-. So, although prior knowledge has some impact on course grades, it didn't seem to stop students from getting good course grades.

Further Study
In future studies, I would like to investigate whether there is a significant difference in scores for students taking the class remotely, and whether and how this relates to how much students know coming into the course (probably through another diagnostic test). I had hoped to study that with my data from Fall of 2024, but too few remote students consented to participate in the study. I would also like to add more optional practice questions for partial differential equations, so that the amount of extra practice available for that subject is in line with the amount of extra practice available for ordinary differential equations and linear algebra. I also want to investigate how much of a role, if any, having taken courses in multivariable calculus, ordinary differential equations, linear algebra, and partial differential equations, plays in course grades, and whether time since having taken these classes has an impact.

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