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Relations Between Prior Knowledge, Learning Support Strategies, and Quiz Scores in a Redesigned 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.

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Overview

This paper presents updates made to Engineering Math I, a graduate-level offered in the School of Engineering and Applied Sciences at the University of Virginia, as part of a long-term goal to increase equity in the course. This course covers topics from ordinary differential equations, partial differential equations, and linear algebra and is taken by students with a wide variety of academic backgrounds—typically mechanical, electrical and aerospace engineering graduate students in their first or second year of study and upper-level undergraduate students. It serves as a broad, encompassing course for the areas of mathematics outside of statistics that faculty members typically want incoming graduate students to understand at the beginning of their academic careers. There are no prerequisites. Because graduate students often come from other colleges and universities and a variety of majors, it is not reasonable to expect that all of them have been exposed to (or have been recently exposed to) the subjects in the course. Thus, it is important that students coming with varying levels of comfort with the course material all have a chance to succeed.

Many studies [2], [1] have been done on the relationship between prior knowledge and performance in math courses within and outside of engineering, finding a moderate correlation or a significant relationship between prior knowledge and student. There is also research [7], [9], [17] on how different study methods can help students with lower levels of prior knowledge. However, the focus is often on undergraduates, especially first year undergraduate students, rather than graduate students.

For this course in particular, a previous study found that students' knowledge entering the course, as measured by a diagnostic assessment, had a significant relationship with their average scores on quizzes that covered partial differential equations, but that there was no statistically significant impact for the ordinary differential equations or linear algebra portions of the course [10]. The course was redesigned to try to mitigate the apparent impact of prior knowledge on student performance on partial differential equations. This study aimed to determine:

1. How, if at all, does graduate students' performance on an engineering math diagnostic assessment relate to their subsequent performance on future quizzes and in the redesigned course? How do patterns of performance compare between the original and redesigned versions of the course?

2. How, if at all, do students' learning support strategies in the redesigned course relate to their performance on the diagnostic assessment and their performance on quizzes?

Course Context

Engineering Math I is a flipped classroom. Students watch video lectures outside of class, and in-class time is used for help on weekly worksheets and homework assignments, as well as for weekly quizzes. This structure helps students work on the course content at their own pace, while still being accountable to the material.

Between Fall 2024 and Fall 2025, the course was redesigned in an attempt to improve student outcomes. Because of the results of a previous study, these updates mostly focused on the partial differential equations (PDE) portion of the course.

Timing

In Fall 2024, PDE was the last subject covered. However, this led to students needing to learn the most difficult topics in the course during the point in the semester when they tend to have more demands on their time. In Fall 2025, the order of the material was changed to make the last topic an introduction to linear algebra. This made it possible to finish the PDE material three weeks before the end of the semester. The timing of the topics also changed to give students in Fall 2025 more time than was allotted in Fall 2024 on two of the more difficult subjects. Finally, the timing of each week was changed so that students had more time between when they submitted homework on a subject and when they got quizzed on that subject. Because of this change, they were often able to get feedback on their homework assignments before they took the quizzes in Fall 2025, which was not the case in Fall 2024. This also allowed them more time to review the solutions to the homework questions and more time between submitting the homework and taking the quiz, which might have led to more time to study for the quiz.

Delivery of Content

Between Fall 2024 and Fall 2025, many of the PDE video lectures were rerecorded to more clearly explain points that confused students in previous semesters. Key changes included the explanations surrounding orthogonality of functions, as well as an increased emphasis on using linearity to break a bigger problem into more manageable pieces. Updates were also made to ensure that relevant review material was covered either in video lectures or as part of the worksheets or preceding homework assignments so that students would have exposure to and practice with older concepts before they needed to use them again.

Additional Practice Material

During Fall 2024 and Fall 2025, students had access to optional problems in WeBWorK (a free online homework system) that provided practice with instant feedback. Unfortunately, not many students made use of this resource in either semester. Moreover, there were not many problems in WeBWorK that were a good fit for the PDE portion of the course.

In Fall 2025, four of the homework assignments on PDE were updated to include optional extra problems, some of which came from old quizzes. Solutions to these problems were posted along with the rest of the solutions to the homework assignment. Students were encouraged to try the problems, but the problems were not collected. Finally, for the quiz covering the basics of Fourier Series, which was an especially difficult quiz for students in past semesters, a practice quiz was provided to students before they took the actual quiz.

Methods

Participants

In Fall 2024, 55 students registered for the course and 25 (45.5%) consented to participate in the study. In Fall 2025, 55 students registered and 23 (41.8%) consented. Demographic information was not collected.

Procedure

This study was approved by the Institutional Board for Social and Behavioral Sciences (Protocol # 6885). All students completed a diagnostic assessment on the first day of class. This covered topics from pre-calculus, calculus, ordinary differential equations, and linear algebra that were relevant to the course material. Students were asked not to study for this diagnostic and earned a "free 100%" on a quiz for taking it, regardless of their grade. The questions on the assessment were the same both semesters. For the purposes of this study, only students' grades on parts relevant to partial differential equations (PDE) were considered when calculating their score. Students' weekly quiz scores on material that was relevant to PDE were averaged together to give an average PDE quiz score for the semester.

During Fall 2025, new resources (practice problems, a practice quiz, and an extra review class) were added to the course. On four of the six PDE-related quizzes, students self-reported whether their study strategies included these new resources by completing a checklist on each quiz (see Table 1). They were assured that there was no penalty for not "studying enough" and were offered a small amount of credit for simply answering the question—even if they indicated that they did not study for the quiz. Their checklists were scored as indicated in Table 1; the more active studying methods were awarded more points. To reflect that practicing problems predicts better performance in math classes [7], students received 2 points for attempting practice problems without looking at solutions first and 1 point for looking at solutions and/or attending the extra review class or watching its associated recording. These "Learning Support Scores" ranged from 1 to 11.

Table 1: Self-reported Study Methods and Points for "Learning Support Scores"

Quiz	Self-Reported Studying Method	Points
Quiz 5	Attempted the extra practice problems without looking at the solutions first.	2
Quiz 5	Looked at the solutions for the extra practice problems, but didn't attempt before looking at the solutions.	1

Quiz 6	Attempted the extra practice problems without looking at the solutions first.	2
Quiz 6	Looked at the solutions for the extra practice problems, but didn’t attempt before looking at the solutions.	1
Quiz 6	Attempted the practice quiz without looking at the solutions first.	2
Quiz 6	Looked at the solutions for the practice quiz, but didn’t attempt before looking at the solutions.	1
Quiz 7	Attempted the extra practice problems without looking at the solutions first.	2
Quiz 7	Looked at the solutions for the extra practice problems, but didn’t attempt before looking at the solutions.	1
Quiz 8	Attempted the extra practice problems without looking at the solutions first.	2
Quiz 8	Looked at the solutions for the extra practice problems, but didn’t attempt before looking at the solutions.	1
Quiz 8	Attended the extra review class or watched the recorded video lecture	1

Data Analysis

To address Research Question 1, a simple linear regression was used on students’ scores on the PDE-relevant portion of the diagnostic assessment and their average grade on the PDE quizzes for both Fall 2024 and Fall 2025. For each analysis, the estimated regression line, a scatter plot, and the results of a model utility test are reported.

To address Research Question 2, a simple linear regression was used on students’ “Learning Support Score” and their PDE quiz average as well as on students’ scores on the PDE-relevant portion of the diagnostic assessment and their “Learning Support Scores”. All of this data is from the redesigned class in Fall 2025. For each analysis, the estimated regression line, a scatter plot, and the results of a model utility test are reported.

Results

The relationship between the diagnostic assessment and quiz scores for Fall 2024 and Fall 2025 are presented first, followed by an analysis of the association between the diagnostic assessment and the Learning Support Score, as well as the relationship between the Learning Support Score and the average quiz grade on PDE material corresponding to that Learning Support Score.

Diagnostic Assessment and Quiz Scores

See Figure 1 for a scatterplot comparing students' scores on the PDE-relevant portion of the diagnostic assessment with their average PDE quiz grade in Fall 2024.

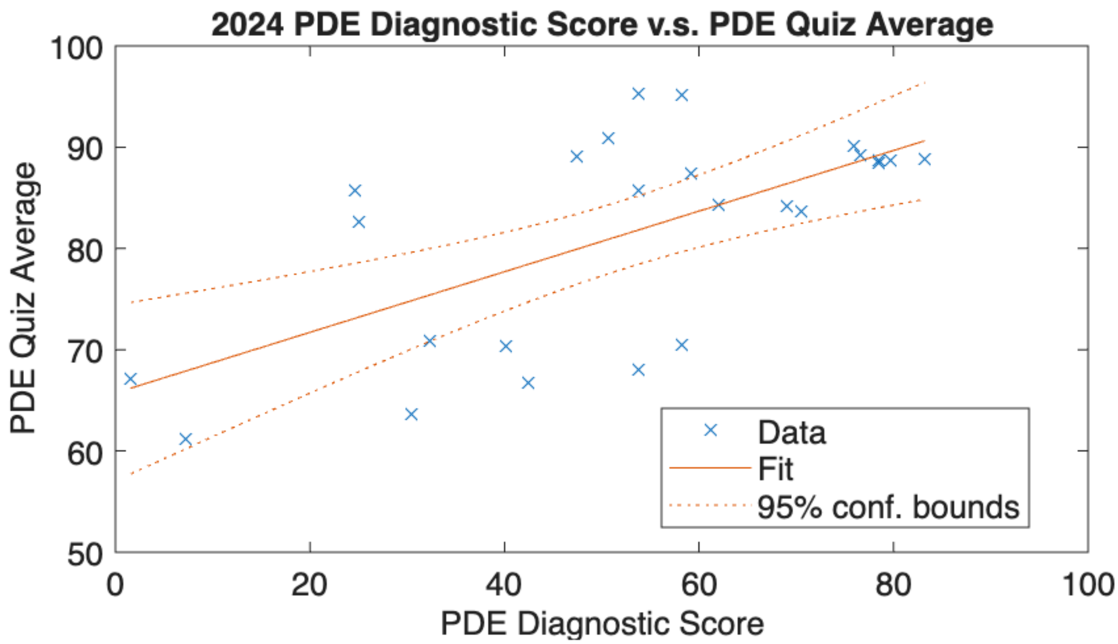

Figure 1: PDE Diagnostic Assessment Scores Plotted Against Average PDE Quiz Scores in Fall 2024

Simple linear regression analysis was conducted to evaluate the extent to which diagnostic assessment score for material relating to PDE could predict students' average quiz score in PDE during the Fall 2024 semester.

A significant regression was found ($F(1,23) = 16.5$), $p = 0.00048$). The R^2 was 0.418, indicating that diagnostic assessment score for material relating to PDE explained approximately 41.8% of the variance in students' average quiz score in PDE during the Fall 2024 semester. Using D for the diagnostic assessment scores relating to PDE and Q for the predicted average quiz score relating to the same topic, the regression equation was:

$$Q = 64.728 + (0.29933)D$$

See Figure 2 for a scatterplot comparing students' scores on the PDE-relevant portion of the diagnostic assessment with their average PDE quiz grade in the redesigned Fall 2025 course.

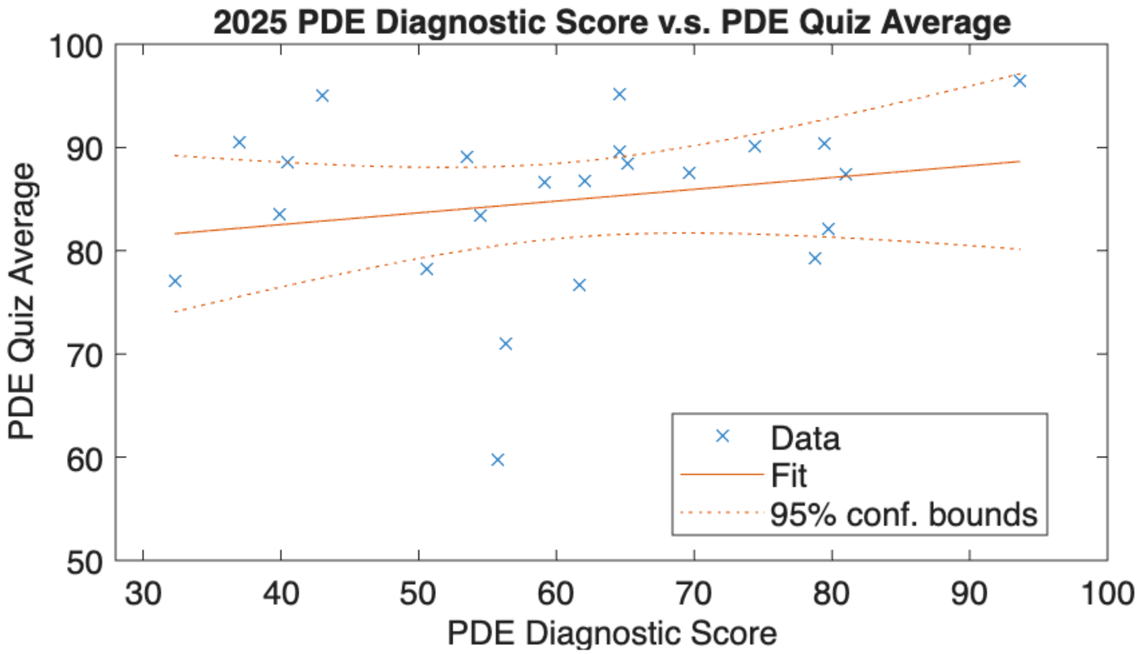

Figure 2: PDE Diagnostic Assessment Scores Plotted Against Average PDE Quiz Scores in Fall 2025

Simple linear regression analysis was conducted to evaluate the extent to which diagnostic assessment score for material relating to PDE could predict students' average quiz score in PDE during the Fall 2025 semester.

A significant regression was not found ($F(1,21)=1.03$), $p = 0.3217$). The R^2 was 0.0469, indicating that diagnostic assessment score for material relating to PDE explained approximately 4.69% of the variance in students' average quiz score in PDE during the Fall 2025 semester. Using D for the diagnostic assessment scores relating to PDE and Q for the predicted average quiz score relating to the same topic, the regression equation was:

$$Q = 77.966 + (0.11395)D$$

The change in p-value for the model utility test on the diagnostic assessment versus students' quiz average in PDE could be an indication that the changes made between these two semesters did indeed mitigate the impact of prior knowledge on quiz performance.

Learning Support Strategies, Quiz Scores, and Diagnostic Assessment in Updated Course

See Figure 3 for a scatterplot comparing students' "Learning Support Scores" with their quiz averages.

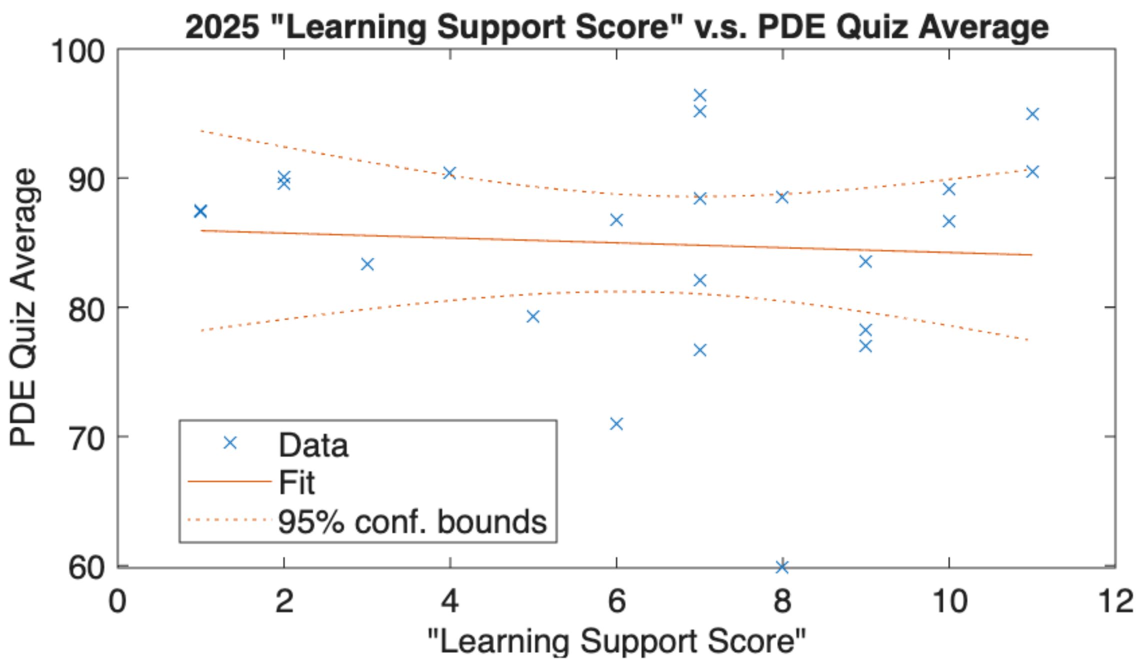

Figure 3: Learning Support Score Plotted Against PDE Quiz Average in Fall 2025

Simple linear regression analysis was conducted to evaluate the extent to which the "Learning Support Score" could predict students' average quiz score in PDE during the Fall 2025 semester.

A significant regression was not found ($F(1,21)=1.101$), $p = 0.306$). The R^2 was 0.048, indicating that the "Learning Support Score" explained approximately 4.8% of the variance in students' average quiz score in PDE during the Fall 2025 semester. Using S for the Learning Support Score and Q for the predicted PDE quiz average, the regression equation was:

$$Q = 86.113 - (0.18783)S$$

Next, see Figure 4 for a scatterplot comparing students' scores on the PDE-specific portion of the diagnostic assessment with their Learning Support Score.

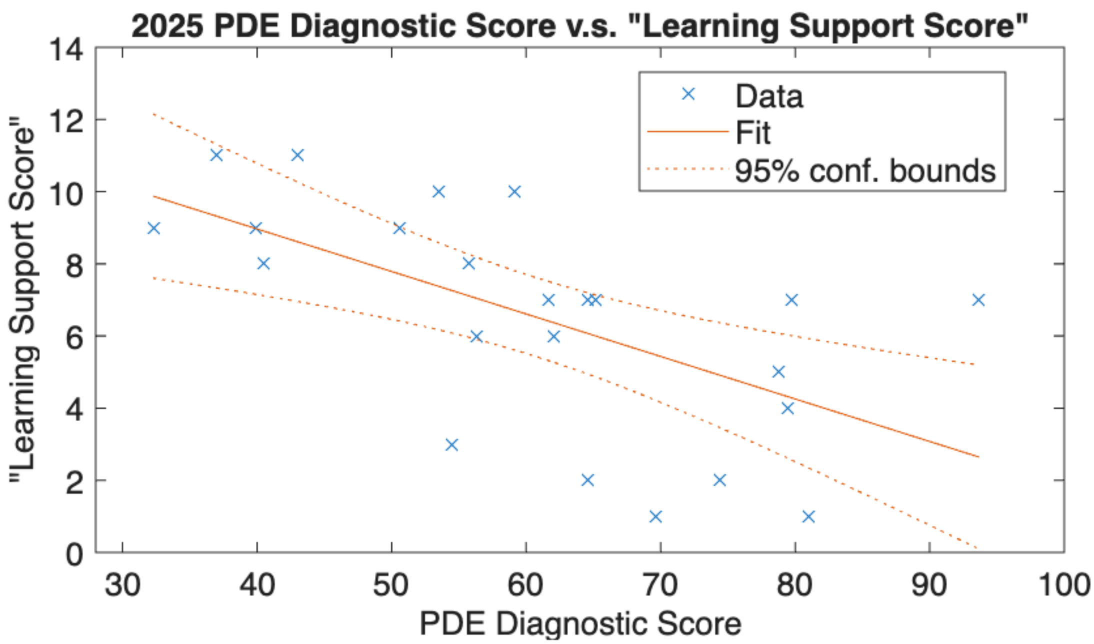

Figure 4: PDE Diagnostic Assessment Score Plotted Against Learning Support Score in Fall 2025

Simple linear regression analysis was conducted to evaluate the extent to which diagnostic assessment score for material relating to PDE could predict students' "Learning Support Score" during the Fall 2025 semester.

A significant regression was found ($F(1,21)=12.3$), $p = 0.00213$). The R^2 was 0.338, indicating thatthe diagnostic assessment score for material relating to PDE explained approximately 33.8% of the variance in the "Learning Support Score" during the Fall 2025 semester. Using D for the diagnostic assessment scores relating to PDE and S for the Learning Support Score, the regression equation was:

$$S = 13.678 - (0.11781)D$$

Conclusions

Redesigning Engineering Math I appeared to make the course more equitable—prior knowledge of PDE as measured by the diagnostic assessment at the beginning of the semester no longer predicted students' quiz performance related to PDE in Fall 2025.

While students' learning support strategies, as measured by the Learning Support Score, did not significantly relate to average quiz score, it did significantly relate to the diagnostic assessment score. Students who scored lower on the diagnostic assessment reported greater use of the optional study resources. While more reported use of the additional materials is not associated with higher quiz scores, the students who did not do as well on the diagnostic assessment were more likely to make use of the optional material. The higher use of optional supplemental material for students with lower diagnostic assessment scores is likely part of the reason that the diagnostic assessment did not significantly predict quiz averages. That is, providing optional supplemental material helped close the gap between students with lower and higher levels of prior knowledge.

Limitations

During both semesters, fewer than half of the students registered for the course consented to participate in the study. Thus, these results might not reflect the students as a whole. Also, because many aspects of the course differed between the two semesters, it is difficult to pinpoint precisely why there was a change between Fall of 2024 and Fall of 2025 in whether the PDE-relevant portion of the diagnostic test score had a statistically significant impact on students' PDE quiz average. In addition to the changes made to the course, the quizzes themselves, as well as who graded them, differed each semester.

Further Study

Future work should examine in more detail how students prepared for each quiz. In particular, questions regarding how much time they spent studying, what combination of active versus passive study strategies they used, and how carefully they looked at solutions and homework feedback help paint a more complete picture of students' learning support strategies. Finally, getting information about how and how much students interacted with their peers to complete the homework assignments and study for the quiz, as well as their interactions with their TAs and professor might provide more insight into how these interactions play a role in student success in the course.

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