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The Role of Prior Knowledge in the Performance of Engineering Students

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Abstract

In engineering, students' completion of prerequisites indicates an understanding of fundamental knowledge. Recent studies have shown a significant relationship between students' course performance and their prior knowledge. Weak knowledge retention from prerequisite coursework can present challenges in progressive learning. This study investigates the relationship between prior knowledge and student performance with a focus on 1) levels of preparedness, 2) perception of preparedness in subjective and objective metrics, and 3) their potential impact on performance. More specifically, the study places students into three groups based on their levels of preparedness from prior knowledge and identifies how these different student groups perform in a Statics Engineering Mechanics course. Statics is considered the subject of interest since it is an introductory engineering course upon which many subsequent analysis and design courses rely. Two types of data (i.e., quantitative and qualitative) were collected to represent the students' preparedness levels. Quantitative preparedness data was collected through a quiz set taken in the first lecture of the course, while qualitative preparedness was collected by a survey. Students' performance was quantified through final course grades. One hundred and twenty nine students were grouped into three categories based on their prior knowledge: 1) 85% or higher score, 2) between 60% and 85%, and 3) 60% or lower. The statistical analysis revealed: 1) a moderately significant correlation between students' quantitative preparedness and course performance; 2) a clear limitation in performance of students from the low-preparedness group, such that none obtained a final score higher than 90; 3) a non-significant correlation between qualitative preparedness and final scores (p-value = 0.29); and 4) a non-significant correlation between qualitative preparedness and quantitative preparedness. The first two findings suggest a positive correlation between the preparedness and course performance. The last two suggest that the qualitative preparedness collected by a survey may not be accurate for various reasons, including students' under- or overestimate their preparedness; the time gap between when students acquired the prior knowledge and when they are subjectively assessed, and others. The study finds low-preparedness does not present a significant barrier to obtaining satisfactory performance, but limits academic excellence. It is useful for Civil Engineering instructors to understand the impact of students' previous knowledge on subsequent courses, as well as their academic excellence.

1. Introduction

Recent years have shown high dropout rates in engineering colleges and universities, leading to a burgeoning discussion of both the causes and student success measures (Seery, 2009). According to educational psychology research, lack of prior knowledge contributes to high dropout rates (Casanova et al., 2018). Students with different educational backgrounds, and prior knowledge enroll in courses, and these differences may create challenges for some groups (Denson & Chang, 2009; Tran & Natha, 2007; Yang et al., 2016). For instance, a study by Kurlancer and Hwell, (2012) reports that students with more K-12 academic preparation tend to have greater academic success in college.

Over the past few years, researchers have developed a correlation between prior knowledge and academic excellence. Binder et al. (2019) compared four prior knowledge types with academic achievement for biology and physics subjects. The four types of prior knowledge include the knowledge of facts, knowledge of meaning, integration of knowledge, and application of knowledge. These knowledge types assess the ability of students to process declarative and procedural knowledge. The indicators for declarative knowledge involve the recognition, along with reproduction of information and definition of concepts, which are covered in knowledge of facts and knowledge of meaning. The indicators for procedural knowledge are understanding the interrelations between concepts, as well as solving the problems. These indicators are covered in the integration of knowledge and application of knowledge. The study employed the logistic regression model to assess the relationship between knowledge types and academic achievement. In addition, the study assessed the well-established predictor of academic achievement, i.e., high school grade point average. In the case of physics, knowledge regarding the principles and concepts, along with the application of knowledge to real-world problems, were significant predictors. The significant predictor for biology was knowledge about the principles and concepts.

In a different study, Durandt, (2017) developed a relationship between prior mathematical knowledge and their grades in first-year engineering mathematics courses. The study employed regression analysis, with the regressors being the achievement scores at the end of term 1, term 2, and the first semester. The findings suggested a moderate correlation between prior knowledge and achievement.

Similarly, a study conducted by Bringula et al. (2015) partially rejected the null hypothesis, stating that prior knowledge in mathematics has no significant role in a student's achievement. Later, Derr et al. (2018) developed a relationship between web-based pre-courses in mathematics and reported success in a German university degree program. The study showed that students with high pre-course learning performed significantly better in the first year.

Most of the studies were focused on developing the correlation between prior knowledge and achievement (Zeitoun, 2007). While past studies confirmed general relationships about prior knowledge and course performance, our understanding about these relationships at a finer scale is limited. To advance our knowledge in this aspect, this study takes an in-depth investigation on these relationships using qualitative and quantitative data. The study divided the students into three groups based on their preparedness and analyzed their performances to better understand such relationships. The three groups are as follows:

1. High preparedness group, with a rate of 85% or better;
2. Medium preparedness group, with a rate between 60% to 85%;
3. Low preparedness group, with a rate below 60%.

The results of this study can help answer questions that have not been sought by past studies:

- Do differences exist between the groups (classified by different levels of preparedness)?
- Do differences exist between subjective and objective measures for preparedness?
- Is there any limit for the low preparedness group, compared with the other groups?

A Statics course (CEE 241), one of the most fundamental civil engineering courses, was used to collect data. The sample size of the study includes 129 students. Both qualitative and quantitative analysis were conducted to understand students' prior knowledge. Data were collected in various ways, including a qualitative survey reflecting students' confidence levels on prerequisite materials (qualitative preparedness) and quantitative measurements from a quiz (quantitative preparedness), as well as final grades (course performance).

The rest of the paper is organized into three main sections. Section 2 discusses the objective and scope of the study; Section 3 illustrates data collection and processing for the analysis, along with the techniques. In Section 4, the findings are reported and discussed in detail. Section 5 concludes the findings and provides insights into the analysis.

2. Objectives and Scope

The objective of the study was to investigate the relationship between the prior knowledge and student performance in a Statics course, using qualitative and quantitative data and at a finer scale (by categorizing into groups) instead of analyzing the student group as a whole. Prior knowledge was determined through pre-quiz grade points and self-assessment survey points. Student performance was analyzed using final score points. To gain an in-depth understanding, the study classified the level of student preparedness in three categories, as explained in Section 1. The subject of interest was Statics, as it is fundamental to many courses relevant to Civil Engineering.

The premise of the study was limited to analyzing student preparedness (in two different measures) and its effect on final grades. The study inferred student confidence levels from the

qualitative and quantitative datasets related to student preparedness. However, issues related to the role of an instructor's teaching style or student learning modes were not studied. In addition, the study did not consider students' socioeconomic conditions and their relation to student preparedness. Since the study is concerned with the trends, individual outliers were not considered as unique trends can still be extracted to provide meaningful insights. The study did not factor in the psychological states of the students or instructor, or their implications.

3. Datasets and Methods

This section is divided into three subsections. The first section discusses data collection and preparation. The second section discusses the data analysis in terms of the study sample's basic statistics. The third section discusses the statistical tests employed in the study.

3.1. Data Collection and Preparation

The data collection was implemented using a questionnaire, along with the results of the diagnostic quiz and final examination grade points.

The questionnaire was designed to understand an individual student's confidence level in three specific topics, Trigonometry, Vectors and Calculus from the course's prerequisites, Physics and Mathematics. The questionnaire allowed the students to grade their abilities on a 1 to 10 scale. For the sake of simplicity and consistency in dataset comparison, the designed scale was converted to 100%.
The diagnostic test was divided into two questionnaires, demonstrating students' vector, which requires trigonometry, and calculus-related problem-solving abilities. The Statics class instructor graded the quizzes based on a consistent rubric system. The students were graded at a scale of 0 through 100%. Students' grade points were reported as an average of the two questionnaires. A total of 97 survey questionnaires were included in the study, which is 32 sample points short of the study sample. The discrepancy is due to students not taking the survey or being absent in the initial classes. The final exam grade points of a student are considered as is, and are graded on a scale of 0 through 100%.

The collected data was further classified into high, medium, and low preparedness of the students. The students' preparedness was based on the initial quiz score points and survey points. Students with more than 85% were classified as highly prepared, while students with between 60% and 85% grade points were classified as medium prepared, and students with scores below 60% were graded as lowly prepared.

3.2. Data Analysis

A total of 129 students were considered to evaluate the relationship between students' prior knowledge and performance. The prior knowledge was gauged by the self-grading survey and diagnostic quiz. Table 1 shows summarized statistics for the collected data. The sample sizes for the quiz, survey, and final scores are different due to student absence. These samples were removed from its individual analysis. The mean values of the quiz scores (80.46) are higher than the survey's mean scores (69.07), suggesting that the students underestimated their skills.

Table 1. Summary statistics of the three key variables: Quiz, Survey, and Final score.

	Quiz Scores	**Survey Scores**	**Final Scores**
Num. Records	125	97	129
Mean	80.46	69.07	81.26
Std. Dev.	26.27	17.22	18.88
Min	0	20	0
25% Percentile	71.43	60	77.19
50% Percentile	90	70	85.37
75% Percentile	100	80	92.83
Max	100	100	100

3.3. Statistical Analysis

Two statistical tests were considered for the analysis. A t-test was used to understand the differences between means of the survey, quiz, and final scores. Linear regression was used to analyze the relationship between the three sets of scores (i.e., quiz, survey, and final). Both tests employed 95% confidence intervals. For an in-depth understanding of the effect of student preparedness on class performance, this study discusses the individual distribution plots of high, medium, and low preparedness of students in relation to the quiz and final scores.

4. Results and Discussion

The section discusses student preparedness and its effect on final scores using regression analysis and t-tests. The section is divided into three parts. In the first two, student preparedness related to the quiz and final exam is discussed. The last section illustrates the relationship between students' quantitative and qualitative preparedness.

4.1. Quantitative Preparedness

Figure 2 illustrates the regression analysis of the quiz scores and the final scores. The estimated slope coefficient has a positive sign with a p-value of 1.4e-8. The p-values are shown in parenthesis below the estimated coefficients. This positive coefficient suggests there is a positive correlation between the variables and the p-value<0.05 suggests that the correlation is statistically significant. This initial analysis suggests that higher scores in the initial quiz (better preparedness) are associated with higher final class scores.

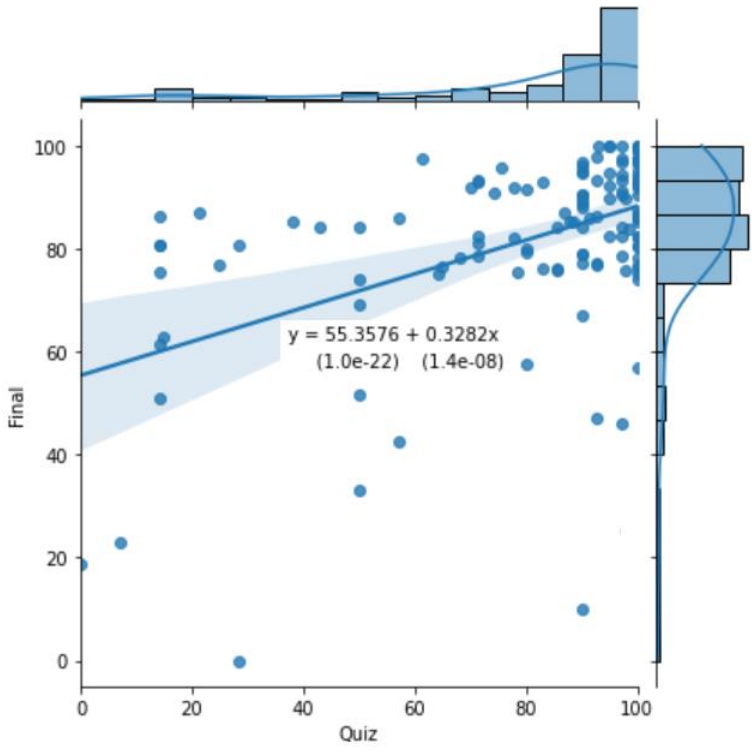

Figure 2. Linear regression analysis between quiz and final scores, along with the distribution of the respective datasets.

To take an in-depth analysis of this relationship, the following analysis compares the difference in average scores across different levels of preparedness. For this purpose, the quiz scores were divided into three categories: low (<65%), medium (65%-85%), and high (>85%) based on the percentage grade points from the quiz scores. Figure 3 illustrates the distribution of final scores based on the three preparedness levels.

The results reveal a few interesting observations as follows:

- Students with high preparedness have a distribution of final scores with high concentration on high values, although some exceptions can be observed.
- A good portion of students with low preparedness were able to obtain relatively high final scores.

- None of the students with low preparedness were able to obtain a final score higher than 90.

The first observation confirms past findings by other research studies. The second finding can be attributed to students that, despite limited past preparedness, were committed to office hours and using available resources to successfully complete the course. The third finding discovers new insight that the initial level of preparedness proved crucial in the academic excellence (over a score of 90 for the final grade) of a student.

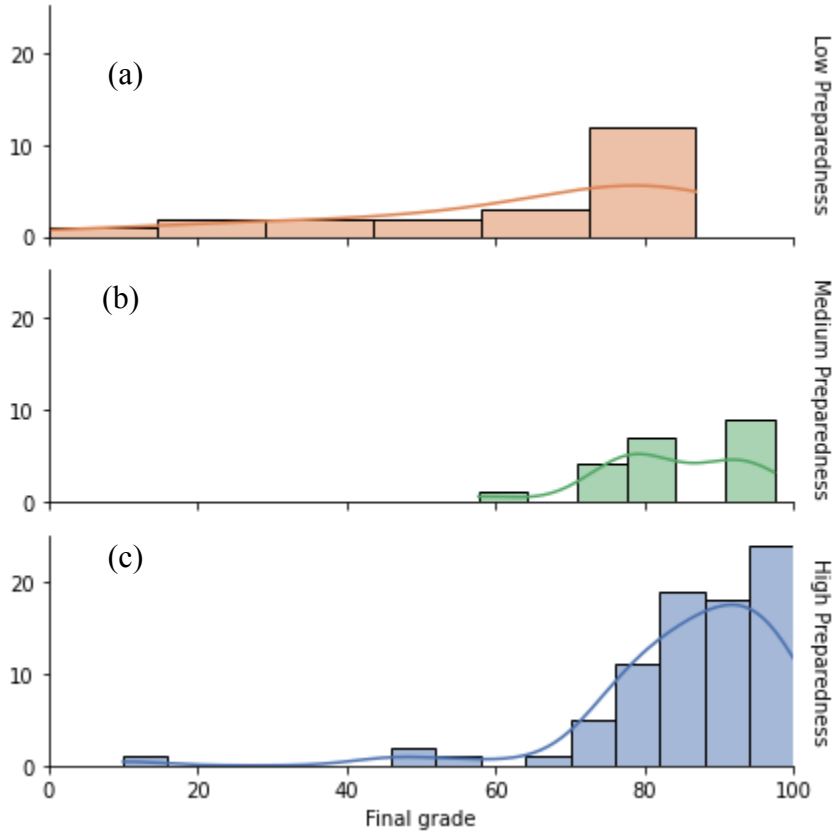

Figure 3. Distribution of final scores for three preparedness levels based on the quiz scores: a. low preparedness (quiz <65%); b. medium preparedness (quiz between 65% and 85%); c. high preparedness (quiz >85%).

A t-test performed on three levels of preparedness further conformed to the observation. The differences in the means of the quizzes and final exams for low, medium, and highly prepared students are presented in Table 2. The comparison of final scores for medium and low preparedness indicates that students with low preparedness have significantly lower final scores than students with medium preparedness, as the p-value for this group suggests statistical significance. In contrast, when comparing mean final scores for medium and high preparedness,

the difference is not statistically significant. This can be interpreted as the medium prepared students can thrive as much as the highly prepared students in a course, which is an interesting insight that have not been identified by past studies.

Table 2. Tests for difference in means of final scores at different preparedness levels.

	Mean Difference	p-value	Significant
Low vs. Medium	20.5	0.001	Yes
Medium vs. High	2.3	0.468	No

4.2. Qualitative Preparedness

A survey was conducted to understand the students' level of understanding on the prerequisites of the course. A high concentration of the students reported their abilities between 50% and 70%, as shown in the distribution of survey scores at the top of Figure 4. On the other hand, the distribution of final scores shows a large proportion above 80% (Figure 4, right y-axis). The behavior was further confirmed by the non-significant relationship between the survey and final exam grades presented in Figure 4 with a p-value of 0.29.

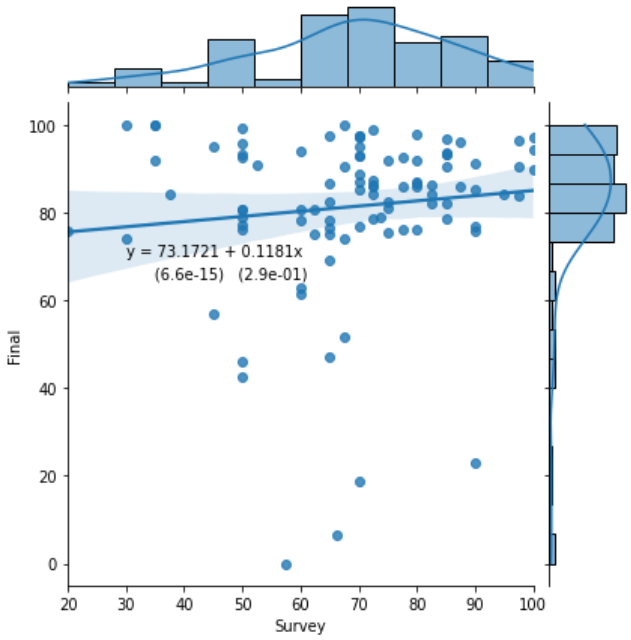

Figure 4. Linear regression analysis between survey and final scores, along with the distribution of the respective datasets.

The study further divided the final scores into low, medium, and high levels of preparedness based on the survey results with the same threshold as discussed in section 3.1. Figure 5 indicates that for any of the three levels of preparedness, there is a concentration of final scores greater than 80, which suggests that most students regardless of their levels of preparedness were able to succeed in the class. This also supports the non-significant correlation between the surveyed and final scores.

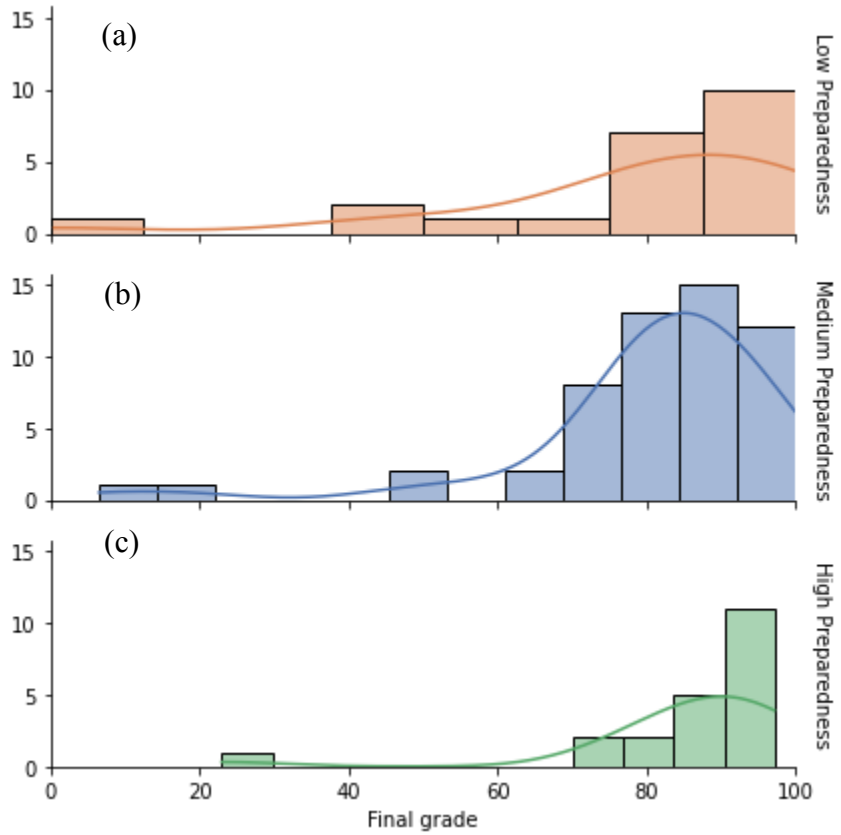

Figure 5. Distribution of final scores for three preparedness levels based on the survey scores: a. low preparedness (<65%); b. medium preparedness (between 65% and 85%); c. highly preparedness (>85%).

Students' miscalculation of their skills and abilities was further confirmed by the non-significant outcomes of the t-test. Table 3 indicates the differences in means of the final scores for different levels of preparedness from the survey scores. The differences in the means were reportedly non-significant for both low vs. medium and medium vs. high dataset groups. Assuming that the survey score self-grading is a proxy to the students' confidence levels, their under-estimations of their skills levels reflects an overall low confidence level in the course prerequisites.

Table 3. The difference in means of final scores for different preparedness levels.

	Mean Difference	p-value	Significant
Low vs. Medium	2.0	0.68	No
Medium vs. High	4.9	0.26	No

4.3. **Relationship between Qualitative and Quantitative Preparedness**

To quantify the differences between the quantitative (quiz scores) and qualitative (survey scores) preparedness of the students, a linear regression (Figure 6) between the two variables was conducted. The objective of this regression is to observe whether there is a significant correlation between the survey and quiz scores. The p-value of 0.30 in the regression coefficient suggests that there is no significant correlation between the survey scores and the quiz scores. An interesting finding is that students underestimated their level of understanding of the pre-requisites for the class as the quiz scores tended to be higher than the survey scores. For the quiz scores, a large proportion of the scores are between 90% and 100%, whereas the concentration of survey scores is between 60% and 80%. This reinforces the researchers' speculation that students underestimated their skill levels in the course.

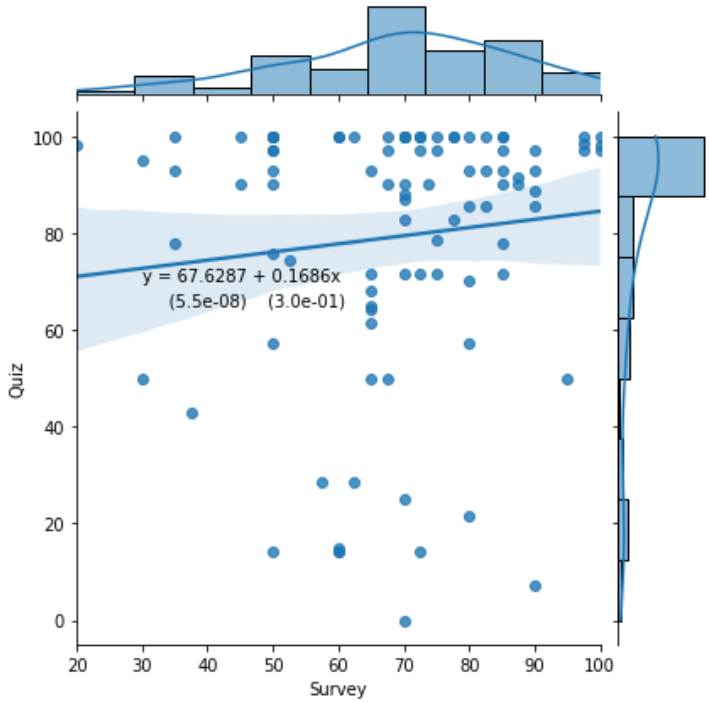

Figure 6. Linear regression of quiz and survey scores.

5. **Conclusions**

The study investigated the relationship between student preparedness and their performance on the final exam for 129 students from an undergraduate Statics course. The study explored this relationship by using qualitative and quantitative data at a finer scale instead of analyzing the student group as a whole. The qualitative analysis involved a self-grading survey with a scale of 1 to 10. The quantitative analysis included the scores of a diagnostic quiz. Both analyses were set up at the start of the semester. To have a deeper understanding of student preparedness and its effect on the final scores, the study classified the qualitative and quantitative data into three levels of preparedness including low, medium, and high. The final scores at the preparedness three-levels were then analyzed through linear regression analysis and t-test at a confidence interval of 95%. The authors note that the sampling of datasets was limited to one institution.

The findings suggest that even (certain percentage) students with low preparedness performed well on final scores; however, their final scores were limited as none of them achieved higher than 90. In addition, the final scores of students with low preparedness were significantly lower than the scores of students from the other two groups. Consequently, despite unwavering motivation, interpreted from frequent visits to office hours and utilization of campus resources, an initial level of preparedness proved crucial a student's academic excellence. On the other end of the spectrum, the difference in mean final scores between students with medium and high preparedness was not significant, which implies that even students with medium preparedness can perform well on final exams.

The non-significant correlation between the survey and quiz scores suggests that students are less confident (based on their self-evaluations) in their understanding of prerequisite classes. This is also confirmed by the distribution in the distributions of the final scores and survey points. The results of this study suggest that students with medium preparedness can also achieve academic excellence and succeed in their classes at a similar level as highly prepared students. From the instructor's point of view, this study highlights the importance of considering a diagnostic quiz at the start of the course. The quiz seemed to provide benefits for both students and instructors by motivating the students to perform better, and at the same time introducing an opportunity for instructors to address misconceptions

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