Paper ID #35797

Creating a First-Year Course to Prepare Mechanical and Aerospace Engineering Students for the Path Ahead

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Session XXXX

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Abstract

The Mechanical and Aerospace Engineering (MAE) Department at the University of Texas at Arlington (UTA) launched a committee to address the rising attrition rates of students in fundamental classes, such as Statics, Dynamics, Fluid Mechanics, and Solid mechanics. The committee compared performance between high achieving and low achieving student populations to evaluate the ever-widening gap in student outcomes. From the initial discussions, the primary contributing factors identified were (a) the impact of COVID-19 on pre-university preparation, (b) poor grasp of fundamental trigonometry, analytic geometry in 3D, vectors, and vector algebra, and (c) lack of problem-solving skills when faced with problems relating to the application of fundamental concepts. Furthermore, the immense diversity in students' academic backgrounds makes it challenging to maintain course pace while ensuring student success. Therefore, the MAE Department created a new, one-hour-a-week course, "Problem Solving in Mechanical and Aerospace Engineering," to address the issues identified. The course introduces fundamental concepts of dimensional analysis, analytic geometry, and vector algebra taught via in-class problem-solving rather than traditional lectures. The goal was to attempt to separate the cognitive processes into smaller “bites” of the basic mechanics of problem solving from their full application in more complicated problems, giving more focus to both individual parts. The problems used are simplified versions of problems the students will encounter in future courses, thereby familiarizing students with the applications of fundamental concepts in a less challenging way.

In this paper, an analysis of the new course will be presented, which includes data on student competency, evaluated via a diagnostic quiz at the start. Further, this work will also compare the outcomes between student groups, such as transfer students versus first-year students and underrepresented minority groups, to ascertain the correlation (if any) between student performance and scholarly background. Finally, the paper will also present lessons learned on the pedagogical methods and identifying students requiring early intervention.

Introduction and Background

Before the fall semester of 2021, the Mechanical and Aerospace Engineering (MAE) department at the University of Texas at Arlington (UTA) evaluated the causes for a growing number of students failing courses such as statics, dynamics, and solid mechanics. They found that the root cause of these issues came primarily from a lack of understanding of coordinate geometry, problem solving, and vector analysis. This problem is not unique to UTA[1-5], but has seemed to become worse since the COVID pandemic started. Further, since UTA is a Hispanic Serving Institute (HSI) with a strong international representation in its undergraduate student body, any intervention would need to use techniques that have been shown to be effective with such a diverse student body. Addressing these concerns within those classes would take more time and take away from being able to teach the subjects within those courses.

Therefore, the department created a new class to address these concerns separately instead of taking valuable time within those other established courses. This course, called MAE 1140, focuses specifically on teaching dimensional analysis, analytic geometry, and vector analysis from an applied viewpoint, using real-life problems rather than abstract concepts. This class was setup to be the first course in the statics, dynamics, and solid mechanics sequence, to be taken within their first year at UTA. Further, the class utilizes techniques used in a past course at UTA, such as active learning and peer instruction methods, that have shown to be highly effective for UTA's diverse student population[6-13].

Methodology

Class format

In order to achieve minimal impact to the length of degree plan, MAE 1140 was created to be a one credit hour, one contact hour per week class. The purpose of the class is to teach basic concepts of dimensional analysis, analytic geometry, vector algebra, and basic multi-step problem solving that are required in statics, dynamics, solid mechanics, and other foundational mechanical and aerospace courses. In so doing, the goal is to make these cognitive processes "bite-sized" to ensure enhanced absorption of these topics. The other goal was to allow other classes to devote more time to their specific topics, rather than also having to teach prerequisite knowledge.

Beginning of semester diagnostic quiz

Table 1. Diagnostic quiz topics and percentage of correct answers from entire class.

Topic Description	Correct Answers (%)
Convert Angles from Radians to degrees	85
Find the values of trigonometric functions of acute angles	75
Fundamental Identities	86
Find the values of the trig functions of an angle, provided information about functions	63
Solve right angle triangles	23
Solve SAA problems using sine law	67
Solve SSA problems using law of cosines	40
Find position vector	76
Add/Subtract vector algebraically	93
Find a magnitude of a vector	67

To gage the academic depth of the class, as well as to adjust the course coverage during the semester, a diagnostic quiz was taken by all the students at the beginning of the semester. In Table 1, the subjects of the quiz are listed as well as the percentage of the class who found the correct answer for each topic.

Originally, the topics chosen were expected to be minimally covered in the course, focusing on application. However, as shown in Table 1, unexpected difficulty with vectors and right angles were found upon analysis, owing to the diverse mathematical preparation of the students as well as the academic setbacks the COVID pandemic caused. Therefore, the course was adjusted to focus more upon the basic mechanics of geometry and vector algebra, with real-life problems rather than a focus on the simple mathematical mechanics that tend to be memorized by students instead of learned. Further, the diagnostic quiz was not given again at the end of the semester and was completely rewritten for Spring 2022.

In-class mechanics

As mentioned in previous paragraphs, a primary focus of the class was applying basic mathematical concepts of geometry, vector analysis, and multi-step problem solving to real-world problems, creating an experiential learning environment. Because of the proven practices of previous works[6-13], the class focused on active learning techniques. These practices include focusing less on traditional lectures and more on actual problem solving inside the class. This was achieved by using mini lectures and allowing students to work on example problems, which then would first be worked by students in small groups and then discussed with the entire class. Additionally, real-world applied examples and practice problems were used, instead of the usual abstract problems and techniques most engineering students receive in other STEM courses. The practices in the class use peer instruction, active learning, and experiential learning techniques shown to aid all students.

Results and Discussion

A quantitative assessment of the class is required to understand the reasons behind student attrition and performance. Three classification measures were utilized to compare and contrast student performance: (1) prior mathematical preparation, (2) academic background, (3) ethnicity. Below we summarize the results based on these classifications. It should be noted that the results come from Fall 2021 from three sections of approximately 40 students. All grades and scores shown come from MAE 1140 only.

Student's prior mathematical preparation

The key requirement of pre-professional engineering courses is a good understanding of basic mathematics, including Calculus, vectors, and Linear Algebra. Student performance was tracked based on their mathematics preparation, as shown in Figure 1 and Table 1. Students who have or are taking Linear Algebra, would have taken Calculus 1, 2, and 3, which means they are assumed to have the most knowledge in mathematics as expected from an undergraduate student. The correlation between math preparation and student outcomes is shown in Figure 1. It is apparent that students who have Calculus 1,2,3 and/or linear algebra background performed significantly better than the rest, with the highest percentage of grade A. Students in Calculus 3, are the next best performers, and the trend follows. The same trend is also seen in the diagnostic quiz performance, where students with better math preparation score higher.

Table 2. Number of students in each Math category

	Calculus 1	Calculus 2	Calculus 3	Linear Algebra	None Listed
Number of Students	25	25	26	31	31

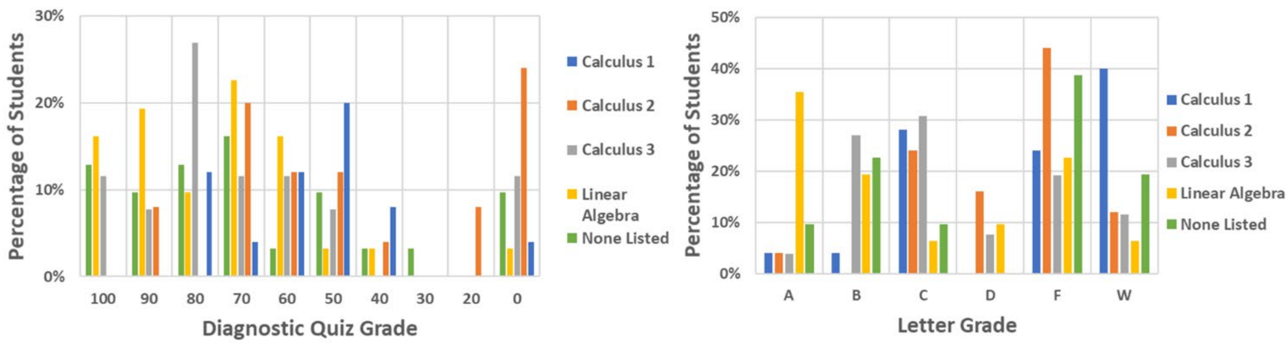

Figure 1: Separates the class by concurrent math class at UTA. The right panel shows the class results, and the left panel shows the results for the beginning of class diagnostic quiz. Zero grade in diagnostics means student did not attempt the diagnostic quiz.

There are two interesting, albeit unsurprising, conclusions that can be made here. First, better mathematics preparation leads to better class performance. Second, and perhaps the more important conclusion, is that we need to re-evaluate when students should be taking pre-professional courses like statics and dynamics. From the data a mere Calculus 1 knowledge, which traditionally is the prerequisite for statics, is insufficient preparation for students to tackle 3D coordinate geometry, and vector analysis. The problem is exacerbated by the fact that many of the incoming domestic students do not have any calculus or vector analysis coursework in high school, causing them to struggle in courses like statics and dynamics.

Student's academic background

Table 3. Number of students in each academic background category

	Freshman	Transfer
Number of Students	44	91

The incoming student population at UTA is diverse in terms of their academic background. A sizable number of incoming students at UTA transfer from community colleges from all around Texas, as seen in Table 1. Transfer students do not join UTA with the same number of credits, which means they do not have the same academic preparation. However, most students would have taken Calculus 1, 2 and/or statics itself. Hence, it was expected that the transfer student would perform better than incoming freshmen calls. This is certainly true for the diagnostic quiz, as shown in the left panel of Figure 2, where the transfer students outperformed the freshmen. Transfer students had a higher average grade on the diagnostic quiz, with almost the same percentage of student scoring at 60% and higher. Freshmen results demonstrate the typical bell curve distribution, with lower average scores on the diagnostic quiz.

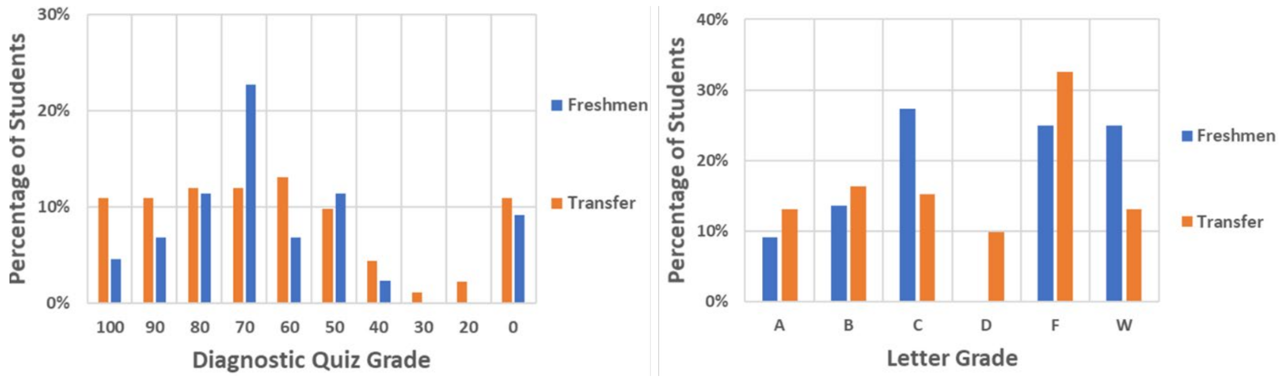

Figure 2: Separates the class by admittance path to UTA. The right panel shows the class results, and the left panel shows the results for the beginning of class diagnostic quiz. Zero grade in diagnostics means student did not attempt the diagnostic quiz.

As would be expected, the bell curve distribution is also seen in the class performance of freshmen students. The same trend, however, is not seen when it comes to class performance, among the transfer students, as seen in the right panel of Figure 2. Even though the transfer students received higher letter grades as compared to freshmen, this group of students also had a higher failure rate than freshmen. The overall results indicate that the transfer student have an edge over freshmen, however, they also have lower outcomes. This indicates that not all transfer students have the appropriate background for engineering courses. A deeper look into the reasons for variation in performance within the transfer student population is required in future works.

Student's ethnicity

Table 4. Number of students in each ethnic category

	Asian	**African American**	**International**	**Hispanic/Latino**	**White**
Number of Students	17	17	16	39	45

As mentioned previously, UTA enjoys a diverse student population, leaning toward our Hispanic population, as seen in Table 4. Student performance with respect to their ethnicity was examined, as seen in Figure 3. In general African-American and Hispanic students did not perform well in both the diagnostic quiz and the letter grade in the class. The performance gap is especially stark within African American students, with none scoring above C grade in class. The reason for such disparity in performance among the minority population could be because of under-par pre-university preparation. However, a more thorough analysis is required in future works.

The importance of good quality pre-university training is highlighted by the fact that international students faired significantly better than domestic students, in both diagnostic quiz and letter grades in the class. In this class, international students comprised of students from south-east Asia, Central and south America, and Africa. Anecdotal evidence suggests that international students would have taken calculus and vectors as part of their high-school curriculum, making them much better prepared for university. This assertion also requires a more thorough study in future works.

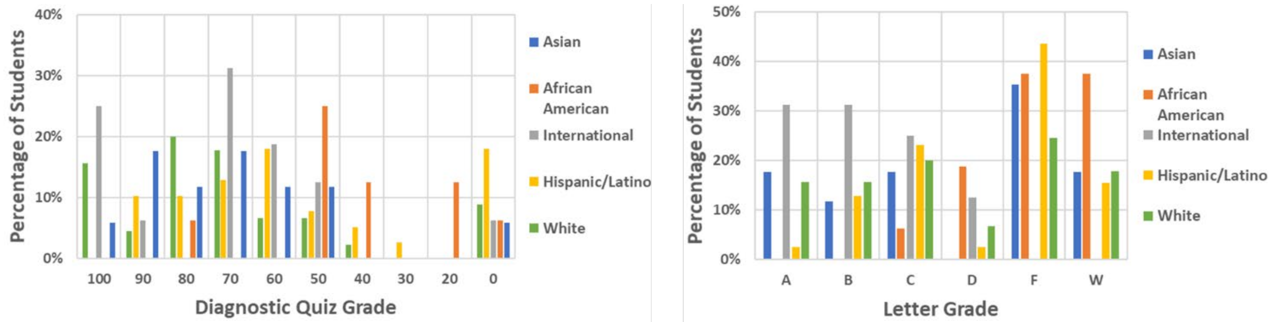

Figure 3: Separates the class by major ethnic group at UTA. The right panel shows the class results, and the left panel shows the results for the beginning of class diagnostic quiz. Zero grade in diagnostics means student did not attempt the diagnostic quiz.

Conclusion

To bridge the knowledge gap between incoming engineering students and the curricular pre-requisites, a new course was developed. With the aim of improving student outcomes, an evidence-based approach to assessment of student performance was initiated. The performance of students from this course will be tracked over their UTA enrollment. This report provides the initial results, which points to the following conclusions and lessons learned:

- In general, incoming students require more attention with regards to fundamental mathematics training in calculus, 3D geometry and vector analysis. Mainly due to their under-par pre-university preparations.
- Student performance is a combination of multiple factors. However, many of these factors point to student's pre-university preparation. Hence, one way to improve student performance is to have a bridge course like MAE 1140, that can bring all students up to par with what is required for courses like statics and dynamics. An early academic intervention is necessary to ensure that students are prepared for pre-professional courses.
- An active-learning problem-solving based curriculum provides a better platform for students. In class group problem solving is found to be effective means to engage students.

Acknowledgement

The authors would like to acknowledge the MAE-CAP committee for their support for the development of the course. The authors are also grateful to the graduate teaching assistants, Sandesh Amgai, Trupti Gosavi, Ananth Jayamani for their effort in assisting with the running of the course.

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