AC 2009-102: A STUDY OF CALCULUS I STUDENTS

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Abstract

A great deal of retention research centers on students entering engineering college and placed in Calculus I. In a University of Michigan research study of first-year engineering retention, the special case of the academic success and retention of engineering students enrolled in Calculus I was considered. In this study, Calculus I engineering students were compared to students in other fields of study (Pre-Med, non-engineering STEM students, and Non-STEM students) who also enrolled in Calculus I as their first math course in college. "STEM" refers to science, technology, engineering and math majors.

From this study, the following research conclusions were made:

1. There was no significant difference in the grade distribution of the engineering students' Calculus I grade compared to students in other fields.
2. A significant difference in the distributions of the first-year GPA (grade point average) existed among the four student sectors with the engineering students showing the distribution with the lowest first-year GPA.
3. There was no significant difference in the retention of students from the first year of college to the beginning of the second year. The retention for engineering students enrolled in Calculus I was 95.6%.

The significance of this research is the comparison of first-year student success performance of engineering students enrolled in Calculus I to students in three other fields of study. This research adds to the literature of similar comparisons of the college GPA, except that this study is specific to engineering students enrolled in Calculus I. While it is significant that Calculus I students in engineering have the same first-year retention rate as students in the other fields, the first-year academic performance was less for engineering students, suggesting that they are at a higher risk for academic probation and eventually dropping out of engineering college. A discussion including the comparison of the first-year STEM GPA distributions is included.

Introduction

Engineering students enrolled in Calculus I as their first course tend to be most at risk for academic success in the first year. Students who AP tested into the second or third Calculus course tend to be less at risk for academic probation due to their more advanced preparation in math and science. Due to the perceived higher risk of engineering students enrolled in Calculus I, there is often more research interest in this group of students. In a single-institution study, this paper discusses the comparison of students enrolled in Calculus I in four student sectors: engineering students, non-engineering STEM students, pre-medicine students and non-STEM students. These four student sectors are compared with respect to the Calculus I grade performance, overall first-year grade performance (GPA) and the first-year retention of these students in the university.

The engineering student sector averaged a lower GPA compared to the other three sectors, consistent with the findings of the germinal Astin and Astin study[1]. Because academic probation is based on the GPA, there was concern about why the engineering students in this study showed a higher percentage of low GPAs compared to other students. Due to the Astin and Astin study and other research studies, it was recognized that engineering students at this institution having a lower GPA was not isolated to this institution but rather a common source of variation relative to engineering academic success across engineering colleges. As part of a larger retention study that included all engineering students in the study, it was found that quantitative skills (as measured by the ACT math, ACT science and placement test scores) was a significant predictor for the GPA for engineering students but not for the GPA for students in the other fields.[2] This research finding led to the consideration of the first-year STEM GPA (GPA of the freshman-level math, science and engineering courses) as a possible explanation of the differences in the first-year GPAs between engineering students and students in other fields. As a result, the distributions of the GPAs of the freshman-level STEM courses (math, science and engineering) were compared across student sectors. The differences in the comparison of the STEM GPA and the overall GPA will be discussed in this paper, with a recommendation for future research.

Based on the research interest in understanding the comparison of the first-year GPA for engineering students enrolled in Calculus I at the University of Michigan compared to students in three other fields, the following research questions were considered:

1) How does the distributions of the first-year GPA and retention of engineering students whose first math course is Calculus I compare to the first-year GPA and retention of Calculus I students in the three other student sectors?

2) Does the study of the freshman-level STEM GPA provide information for the inference of why the first-year GPA for engineering students tends to be lower than that of other student sectors?

Literature Review

The research literature overall strongly suggests a causal relationship between the college GPA and graduation in engineering.[1,3,4,5,6] In particular, in a multi-institutional study that covered nine engineering colleges over 15 years, Zhang et al. found that most students with a low GPA had transferred out of engineering within three semesters. Few engineering graduates had earned a first-year GPA less than 2.000. In their conclusions, Zhang et al. stated, "We hypothesize the causal link that student self-efficacy improves with academic success and self-efficacy lead to improved retention."[6] In contrast, the Seymour and Hewitt study found no strong relationship between academic performance and retention in STEM programs.[7]

Within engineering, Calculus I is considered a gateway course to success in engineering. Correct placement into either Pre-Calculus or Calculus I has received substantial research. Because of the calculus content in the majority of engineering courses, successful completion of Calculus I, with a very good to excellent understanding of the calculus concepts is important for other courses in the freshman engineering year. In general, it is expected that students enrolled in Pre-Calculus and Calculus I in the first semester are the most at risk for persistence in engineering. In a University of Michigan study by Koch and Herrin, it was found that students with an A to B grade in Calculus I had a 74% six-year graduation rate versus a 54% graduation rate for students with a B- to C grade in Calculus I.[8]

In this paper, a comparison is made in the first-year GPA and first-year retention for engineering students versus three other student sectors. Although no literature comparisons were found across majors for the first-year GPA and retention, significant literature relative to the comparison of engineering students to students in other fields with respect to grades were found. Astin and Astin reported that engineering students earned a lower GPA than did students in other majors.[1] Ohland et al. compared the grade distributions of engineering students to other majors using two sources of data: MIDFIELD and NSEE.[9] In the MIDFIELD (Multiple-Institution Database for Investigating Engineering Development) student data came from nine southeastern universities in 2007. The NSEE (National Survey of Student Engagement) was a national survey conducted in 2006 of 534 educational institutions in the United States and Canada. Using MIDFIELD and NSEE data as sources, the researchers found no significant difference in the overall grade distributions among several majors, including engineering (using a Chi-square test).

Specifically, there was no difference in the self-reported grade distributions of freshmen by major in the NSEE survey when all majors in the study are considered. However, when engineering responses are compared to just the arts and humanities students, they noted that "engineering students reported having 'C' GPAs more frequently than arts and humanities students" in the NSEE survey ; 14.6% of engineering freshmen earned a 'C' GPA compared to 8.2% for arts and humanities majors (Table 11 of Ohland et al.)[9] Correspondingly, it was also reported that "NSSE freshmen… reported having 'A' GPAs notably less frequently than students in arts and humanities, but with similar frequency to students in other areas of study." For freshmen, it was reported that 37% of the engineering freshmen reported an 'A' GPA compared to 46% of the arts and humanities freshmen (Table 11 of Ohland et al.).[9] In contrast, Zhang et al. found that engineering students had a significantly higher college GPA than non-science disciplines and about the same as science majors.[10] Ohland et al. also reported no significant difference in 8-semester retention with the MIDFIELD database, with engineering students having the highest retention.

Both the Astin and Astin study and the Seymour and Hewitt study indicate that engineering courses tend to have competitive grading and "grading on the curve."[7, 11] Astin reported, "engineering faculty are about twice as likely as faculty in other fields to grade on the curve." Astin explains the concept of grading on the curve as: "Grading on the curve artificially rations good grades because it limits the number of high grades without regard to the absolute level at which students are performing."[11] This raises the question whether to expect a difference between the GPA of STEM (science, math, technology and engineering courses) and the overall GPA.

Methodology

This study of Calculus I students is part of a larger freshman retention study[2, 12] at the University of Michigan. The sampling of students is based on individuals who participated in the UCLA/HERI Cooperative Institutional Research Program (CIRP) survey and gave permission for their data to be used in research (an IRB requirement).

The overall sampling rate was 30% for the two freshmen classes that were surveyed (2004 and 2005 freshmen classes). An analysis by freshman class, gender and race showed a consistent representation, close to the overall sampling rate for that year. The one major exception was a low representation of international students in the sample (refer to page 82).[12] A comparison of the 50% mid-range of ACT and SAT scores for the 30% sample compared to the entire freshman class showed good correlation. This comparison included all student sectors. For the 2004 sample, the SAT math 50% mid-range was 620-710 in comparison to 630-720 for the entire 2004 class. For the 2005 sample, the SAT math 50% mid-range was 630-720 in comparison to 630-730 for the entire 2005 class (refer to page 86).[12]

First-year student performance data were linked to the survey records. Because of the structure of the larger study, the GPA analysis is based on the 2004 cohort and the retention analysis is based on both the 2004 and 2005 cohorts. Only the first-time, full-time students were included in this study.

Definitions

This is a single-institution study with a comparison of the engineering freshmen to three other student sectors within the university. The four student sectors are independent and are defined as:

Engineering: this sector includes students who were admitted to and matriculated into the College of Engineering.

Pre-Med: this sector includes students who indicate in the CIRP survey that their most probable career choice was a physician, exclusive of the College of Engineering.

STM: this sector includes all science, math and technology majors exclusive of the engineering and pre-med groups using the CIRP variable, “most probably major”.

Non-STEM: this sector includes art, music, social science, business and humanities majors, using the CIRP variable, “most probable major”.

Two GPAs are defined as:

Overall GPA: This is referred to as the GPA (grade point average) and is the grade point average for all courses taken in the first year of college.

STEM GPA: This is the grade point average for all 100-level (freshman) science, math and engineering courses taken in the first year of college.

Note: grade point averages (GPA) are calculated based on a 4-point scale.

Other definitions include:

The cumulative distribution for the GPA and STEM GPA: this distribution measures the cumulative percent of students with a particular GPA or less. For example, a 30%

cumulative percentage for a GPA of 2.5 indicates that 30% of the students earned a GPA of 2.5 or less and 70% of the students earned at least a 2.5.

The university retention: this is the first-year retention of students within the university; i.e. these students returned for the fall term of the sophomore year. For a consistent retention statistic across all student sectors, the retention percent was calculated within the university (transfers within the university included).

Results and Discussion

There was no statistically significant difference in the Calculus I Grade Distributions

Figure 1 shows the box plots of the grade distributions for each student sector. Included in these distributions were students who were full-time freshmen enrolled in Calculus I as their first course in math during the freshman year. Students are placed into the Calculus I course based on the math placement tests.

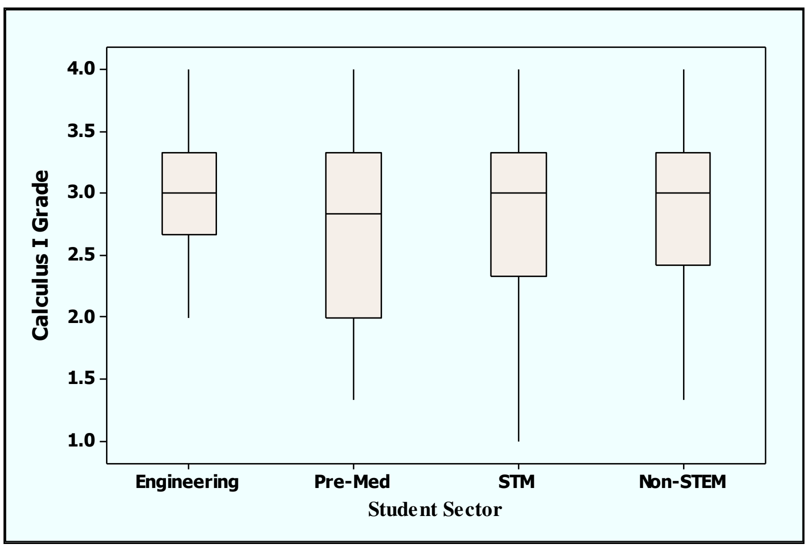

Figure 1: Box Plots of Calculus I Grade by Sector Show No Statistically Significant Differences (combined sample size equals 179)[12]

The box plots show consistent medians and variation in the mid-range. Due to a concern about non-normality of the distributions and unequal variances, the non-parametric Kruskal-Wallis test for comparison of the distributions was used. The Kruskal-Wallis test showed no statistically significant difference in the distribution of the Calculus I grades among these four student sectors (p=0.413). Using the ACT math scores as an indication of preparation levels, there also were no significant differences in the distribution of the ACT math scores (p=0.193). These statistical results of no statistical difference tend to support the effectiveness of the placement test across all student sectors.

Ranking Comparisons of Student Sectors is Different for the STEM GPA Compared to the Overall GPA

Table 1 displays the average, median and standard deviation of the first-year STEM GPA and first-year GPA for each student sector. Among the four sectors, the engineering sector has the highest average STEM GPA and the lowest average overall first-year GPA. A comparison by the median statistic shows that the engineering and STM sectors have the highest median STEM GPA and the engineering sector has also has the lowest median overall GPA. Significantly, the engineering sector shows the smallest standard deviation of the four sectors for the STEM GPA and the largest standard deviation for the overall GPA, indicating more variation in engineering students' overall GPA

Table 1: Student Sector Statistics for the First-Year STEM GPA

Student Sector	Number of Students	Average	Median	Standard Deviation
First-Year STEM GPA				
Engineering	56	2.909	2.941	0.518
Pre-Med	28	2.875	2.881	0.522
STM	47	2.862	2.955	0.682
Non-STEM	48	2.886	2.876	0.687
First-Year Overall GPA				
Engineering	56	3.000	3.024	0.504
Pre-Med	28	3.199	3.239	0.329
STM	47	3.185	3.244	0.488
Non-STEM	48	3.273	3.267	0.427

In Figure 2, the cumulative distributions of the first-year STEM GPA and overall GPA of the four student sectors are shown. Differences were found to exist between the two distributions. Figure 2 (top) showed no significant difference among the four sectors for the cumulative distributions of the STEM GPA using the Kruskal-Wallis test. At the low end of the scale for STEM GPA, the Engineering sector shows the highest distribution of the STEM GPA (lower percent of low STEM GPAs and to the right of the other distributions).

In Figure 2 (bottom), there was a significant difference in the distributions among the four sectors. (The non-parametric Kruskal-Wallis test was used to determine significance.) As has been indicated, the engineering sector exhibited the lowest distribution of the overall GPAs with the lowest median and the highest percent of low GPAs (See Figure 2, bottom graph). Since a GPA less than 2.000 defines academic probation, Figure 2 suggests that the engineering students were at a higher risk of probation and dropping out of the university than other student sectors. From this figure, it becomes clear that the concern about Calculus I students and retention in engineering is valid.

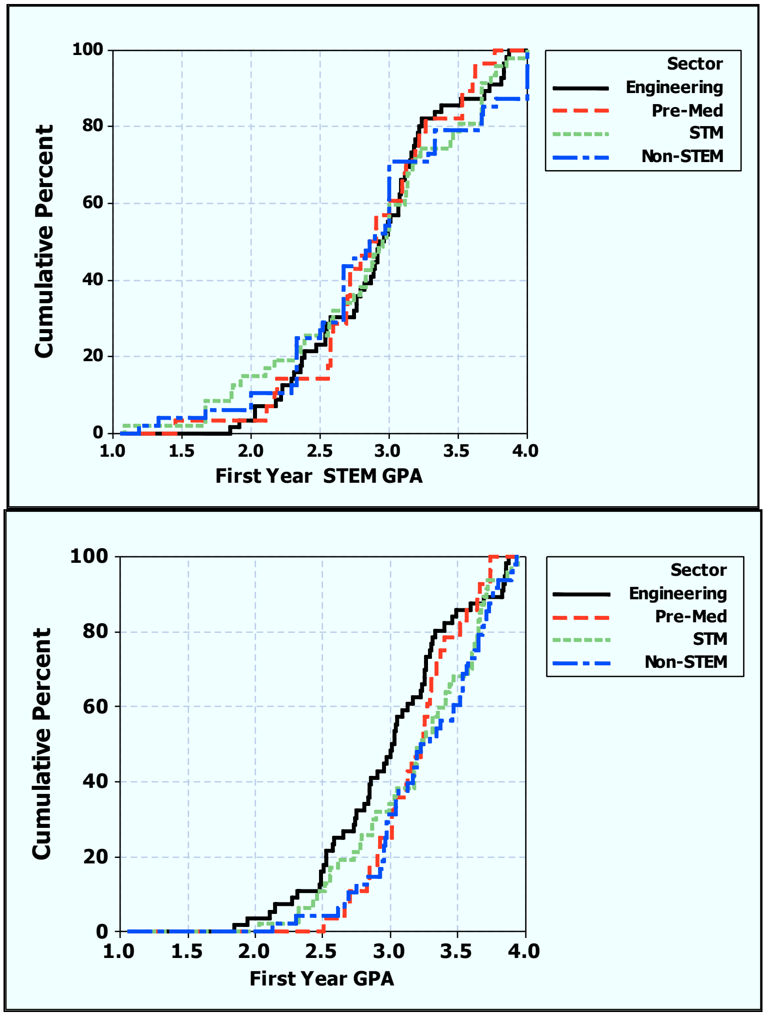

Figure 2: Cumulative Distribution of First-Year STEM GPA (top) and First-Year GPA (bottom) for Calculus I Students Show Differences in Sectors. The combined sample size is 179.[12]

Table 2 summarizes Figure 2. A GPA of 2.5 is used as a comparison because it is an indicator that a student may be at risk for a lower GPA and academic probation. The Engineering student sector showed the highest percent of students (18%) earning a first-year GPA less than 2.5 compared to the non-Engineering sectors (13% for the STM sector, 4% for the Pre-Med and Non-STEM sectors). For the STEM GPA, the percent of engineering students with a STEM GPA less than 2.5 was 23%, in the midrange of 14-27% for all sectors.

Table 2: Percent of Calculus I Students with a GPA < 2.5 for the Overall and STEM GPA

Student Sector	Percent of Students With GPA <2.5
First-Year Overall GPA	
Engineering	18%
Non-Engineering	4-13%
STEM GPA	
Engineering	23%
Non-Engineering	14-27%

In this study, a different approach was taken to understand the overall first-year grade distributions. A STEM GPA that included only the freshman-level (100-) courses in science, math and engineering was calculated and compared across the fours sectors. The research question was whether the calculation of this STEM GPA would provide information for the inference of why the first-year GPA for engineering students tends to be lower than that of other student sectors. In comparing the two graphs in Figure 2, the distribution for the engineering students stays about the same (between the STEM GPA and GPA graphs), while the distributions of the non-engineering sectors shift to the right on the GPA graph. The inference then is that the grading scale for the STEM courses is more competitive than for the non-STEM courses.

Note: A similar analysis was conducted for all students including students who started in Calculus II or Calculus III (by AP test placement). The results were similar for the comparison of the distributions of the overall GPA across the four student sectors. For the comparison of the STEM GPA, there was more variability leading to a significant difference in the distributions using the Kruskal-Wallis test. The Engineering student sector showed the highest STEM GPA median of the four student sectors (see page 234 of reference 12).

No Statistically Significant Difference in the University Retention Rates of Calculus I Students Among the Student Sectors

Figure 3 displays the 95% confidence intervals on the university retention for each student sector. For students who enrolled in Calculus I, there was consistency across the four student sectors for university retention with no significant differences. In addition, all four confidence intervals include 96.4%, the university retention rate of Calculus I students for all sectors, supporting that the retention rates were statistically the same. In comparison, for all students in the larger study, the university retention rate was 97.6%.

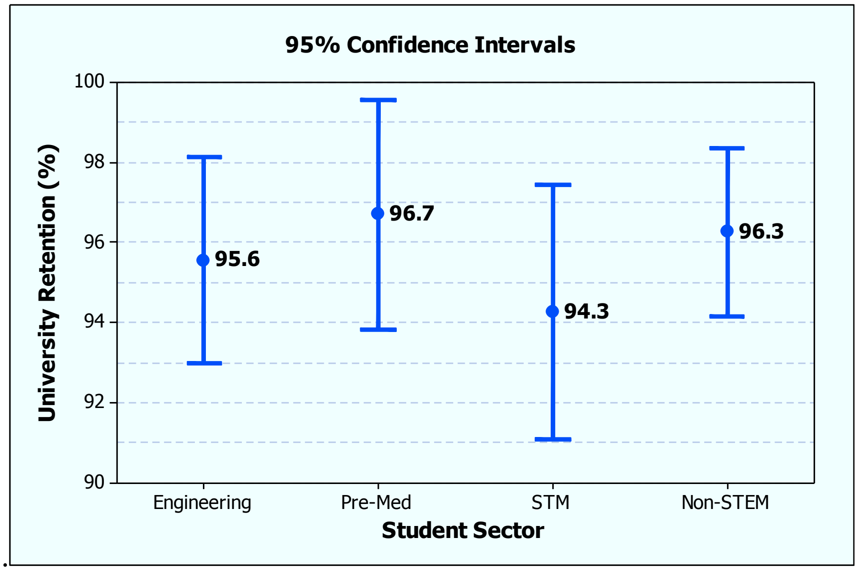

Figure 3: No Difference in Retention Among Sectors for Calculus I Students (combined sample size equals 930)[12]

Conclusions and Recommendations

The first research question was whether there would be a statistically significant difference in the first-year GPA and first-year retention. It was found that there were differences in the first-year GPA with the engineering sector having the lowest average and median. Significantly, there was no statistically significant difference in the first-year retention among the four student sectors. All student sectors retained Calculus I freshmen into the second year of college at the same approximate retention rate of 94 to 97%. Any retention rate over 90% is considered exceptional.

Since Calculus I is a gateway course for engineering, the fact that the first-year retention of the Calculus I students in engineering is the same as other student fields is significant information. It is suggested that this engineering college has a number of freshmen programs and policies that support students, especially students who are close to academic probation, leading to a high first year retention rate. There is still the strong possibility of a causal relationship between the GPA and the engineering graduation rates, as was indicated in the literature review.

The second research question asked if the study of the first-year STEM GPA contributed to understanding why the Engineering sector has a lower first-year GPA than the other student sectors. The answer to this question is yes. It appears that the first-year STEM GPA is more consistent among the four student sectors and it can be inferred from Figure 2 that the grading of the STEM courses is more competitive than the non-STEM courses. Although the literature review suggested that the practice of grading on the curve may be an issue, insufficient evidence was available to make this inference for this study.

Often, in engineering education, there is a major concern with engineering students enrolled in Calculus I having a higher risk academically in engineering. Since engineering students tend to enter engineering college with higher average SAT or ACT scores than most other majors, this seems counter-intuitive. Assuming, as presented in this study, that the university has a reliable placement process into Calculus I, it can be expected that some engineering students will be placed into Calculus I. Many of these students will not have had the opportunity to take calculus in high school. Most of these students will have ACT/SAT math scores in the lower range of all engineering students. This study confirmed that it could be expected that they will perform just as well academically in the calculus course as other majors and not necessarily better. The placement tests measure preparation and although the engineering class as a whole has a better preparation as measured by the ACT or SAT math scores, the students who are placed into Calculus I all have a similar knowledge of pre-calculus or some basic calculus concepts.

Although it would be desirable that engineering students enrolled in the first calculus course would achieve higher academic grades in calculus, this cannot be expected without extra intervention (i.e. tutoring, mentoring). The teaching/learning process of the Calculus I course will generate A's, B's, C's and D's for engineering students as well as for other majors. Yet, assuming that grades are an indication of what was learned, it is imperative that most engineering students earn an "A" or an "B", due to the need for this knowledge in subsequent calculus-based courses in the freshman engineering curriculum. This discussion supports the need for more tutoring and mentoring of freshman engineering students in Calculus I as an intervention strategy for student success than for students in other fields.

With the comparison of the distributions of the STEM GPA and the overall GPA for Calculus I students at this university, the difficulty that Calculus I students are having in their other freshman-level courses becomes clear. For this study, it appears that the STEM courses produce a more rigorous grading scale (more low grades) than the non-STEM courses, leading to a lower overall GPA distribution for the Engineering sector. A review of Figure 2 shows a lower scale for the STEM GPA than for the overall GPA. Across all sectors, the range on the percent of students with a STEM GPA less than 2.500 is 14 to 27%. Yet, for the Non-STEM and Pre-Med sectors, only about 4% of the students have an overall GPA less than 2.500 and about 18% of the Engineering students have an overall GPA less than 2.500.

The literature is divided on whether engineering students show lower or higher GPAs than other majors. In the Astin and Astin study, evidence was presented that the GPA of engineering students was less than for other majors Zhang et al. found that engineering students had a higher GPA. Ohland et al. found no difference in the grade structure compared to other majors in the MIDFIELD data and a lower percent of 'A's for engineering students compared to the arts and humanities majors from the NSEE data.[1, 10, 9]

This disparity in the literature and the analysis in this paper raise the question of whether engineering students have a higher or lower GPA than other majors may be due to the number of STEM courses that are included in the overall GPA. Perhaps, in programs where engineering students take almost all STEM courses, a GPA less than other majors may be expected. Where there is a balance of STEM and non-STEM courses, the GPA may be about the same or more than that of other majors.

Why is this important for our understanding of first year engineering academic success? The overall GPA is the basis for academic probation. Usually academic probation is indicated with a

GPA less than a 2.000. In the engineering education literature, there is much more discussion of students being on probation than in the general college education literature, indicating that this issue is more of a trait of engineering education.[13] If the first-year STEM GPAs in this study is representative of most engineering colleges, it can be concluded that further research is needed on this topic.

This study had a limitation as a single-institution study. In future engineering education research, it is recommended that other researchers consider the calculation of the freshman-level STEM GPA and compare it to the overall GPA across majors of university freshmen. It is hoped that the ideas discussed in this paper add to a further dialogue on first-year engineering student success.

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