Investigating Calculus as a Barrier to Entrance to Major in a Mechanical Engineering Technology Program (WIP)

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Introduction

Calculus is often identified as a barrier to student success in engineering and engineering technology programs. In previous research, overall success in the Mechanical Engineering Technology (MET) program at Penn State Behrend was assessed in relation to students' success in introductory engineering graphics courses [1]. That work found a significant correlation between success in engineering graphics courses and successful completion of the major. At Behrend, enrollment in the MET program is contingent upon a student's successful completion of a specific subset of courses taken during the first two years of study: college algebra, technical calculus, and algebra-based physics. This earlier work also examined the relationships between the entrance to major (ETM) requirements of physics and calculus and student success, finding that success in the major had a significant correlation with success in physics courses and a statistically significant, but appreciably weaker, correlation with success in calculus courses.

The initial study involved only 75 subjects. Due to the lower correlation between student success and performance in calculus, further study was pursued with a larger group of students. Data have been collected on ten years of graduates of the bachelor's degree MET program at Behrend to assess the relationship between overall student success and success in entrance to major calculus courses. This paper also looks at the correlation between other major-required courses and overall success in the MET program to recommend a combination of entrance-to-major courses that better predict overall student success.

Calculus Requirements Across Programs and Institutions

Calculus I is typically the entry-level mathematics requirement for many engineering and engineering technology majors. In a review of ten different ABET-accredited MET bachelor's degree programs of varying sizes across multiple institutions, six of the ten programs listed Calculus I as the first required mathematics course in their curriculum. Two, including the program at Behrend, required trigonometry as the first mathematics course, one started at algebra, and one at pre-calculus. Although it is not the first required mathematics course in the curriculum, calculus is used as an entrance to major (ETM) requirement at Behrend. Students who meet Behrend's math department's math proficiency standards for calculus are allowed to start their studies with that course and do not have to take the trigonometry course. Some students entering the program do not start their studies in calculus or even in trigonometry, but at lower levels of mathematics. Such courses include College Algebra and "Technical Mathematics," which is a review of algebra, functions, systems of linear equations, and an introduction to trigonometry.

Behrend has several alternate pathways through the required mathematics sequence in place for students. Starting mathematics at a level lower than trigonometry can result in a time to graduation that is longer than the expected four years, but it does not, by default, prevent success

in the major or extend the time to graduation by more than one semester. Considering only students who maintained full-time enrollment at Behrend, the median time to graduation for students not starting their studies in calculus was nine semesters. Multiple situations factored into the extra semester, though, including taking a semester off for a co-op or internship and needing to repeat courses other than calculus.

In programs that start with calculus, some studies [2], [3] have found that students who earn passing grades in their first mathematics course, and continue in an engineering program earning a C or better in the subsequent courses, are many times more likely to succeed in the major than those who start at a lower level course or have to repeat their first calculus course. Studies have found similar results for engineering technology programs [4]. There are often multiple 'barrier courses' that can inhibit student success, including physics and chemistry, but mathematics is often the most influential when determining retention in an engineering program [5]. In many institutions, there is little room for innovation or flexibility in the mathematics requirements, and there is often not a well-planned alternative path toward graduation for students who do not start in, or do not initially earn a passing grade in, their first required calculus course. Lee et al. [6] found that using mathematics diagnostic or placement tests is not always a good predictor of student success across populations and institutions, and institutions need to develop their own models based on their student population because of the large number of factors that cannot be built into those models, including student preparation and motivation. But many institutions rely primarily on standardized test scores such as ALEKS, the SAT, or ACT for placement without considering those other factors. A study of over 3,000 engineering students at a public research university found that students starting their studies in a trigonometry course – considered remedial mathematics for engineering students that institution – were less likely to stay in engineering even if they earned an A in the trigonometry course [7], but concluded that there was a need for additional qualitative work to see to what extent the barriers to success were structural or motivational.

Materials and Methods

Currently, to be eligible for entrance to major, (ETM) an MET student at Behrend must have a minimum of a 2.0 cumulative GPA, and a grade of C or higher in an introductory physics course and a calculus course. The requirement exists even though lower division major courses do not require either calculus or physics as a prerequisite. Although multiple courses in the MET major also require an earned grade of C or above to count for credit towards graduation, currently, no major-area courses are used as ETM requirements. The physics required in the MET curriculum requires college algebra or trigonometry as a prerequisite. Some students at Behrend take a different physics course that has a calculus prerequisite; those courses are included in this study and are primarily taken by students who have transferred from other majors, including mechanical engineering, or who have transferred from other institutions.

After obtaining IRB approval, the campus registrar provided ten years of data, which yielded 325 graduates of the 130 credit-hour bachelor's degree MET program at Behrend. Overall GPA was provided, along with grades in multiple courses. The courses assessed for their relationship to overall student success in the major include Mechanics for Technology: Statics; Manufacturing

Materials and Processes; Dynamics; Strength and Properties of Materials; Applied Solid Modeling; calculus courses that met ETM requirements, including Technical Calculus, and Calculus with Analytic Geometry; physics courses that met ETM requirements, including Introductory Physics I, and General Physics: Mechanics. The majority of the ten mechanical engineering technology programs from other institutions reviewed for this study include courses in engineering graphics, materials and processes, statics, dynamics, and strength of materials, along with calculus and physics, in their first two years. Two programs did not require courses specifically in the topic of engineering graphics, and one did not require dynamics as a lower-division course. Entrance to major requirements varied widely.

Research Hypotheses

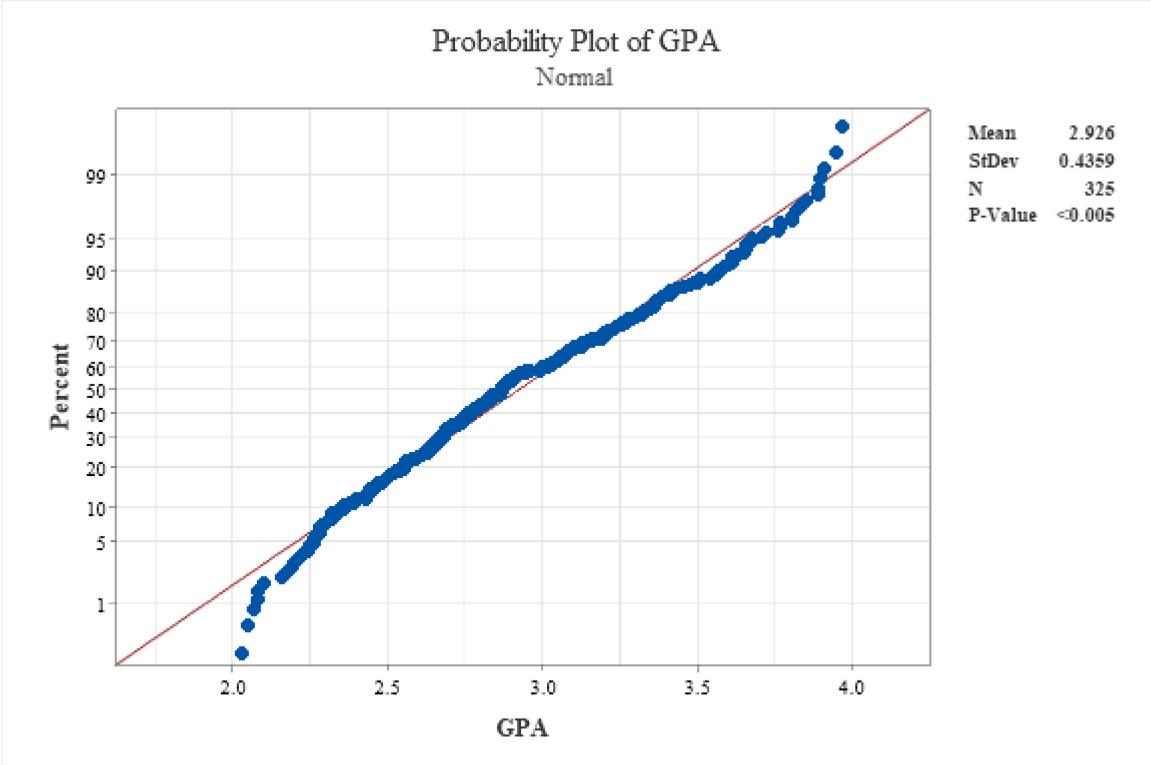
Although there is debate about the appropriateness of using a student's GPA as a measure of success, the GPA is nevertheless a requirement for entrance to major consideration at Behrend and many other institutions. While a student's assessed performance on any standardized measure of a topic or content may be different from their graded performance in a related course, the use of the GPA is a requirement by the administration at Behrend, and departments cannot enroll or deny a student based on non-GPA data. Therefore, the overall GPA of ten years of MET graduates from Behrend was analyzed, along with grades in multiple first and second year major courses, and in calculus and introductory physics.

Only earned grades were included in the analysis; transfer credit and pass/no pass grades that were in effect during COVID-19-impacted semesters were omitted. The data were collected from a total of 325 graduating students over ten years at Behrend. During that time, there were minor changes in the curriculum, but the requirement of passing a calculus course and a physics course for ETM did not change. The program maintained continuous accreditation by ABET during that time.

- Hypothesis 1 – there is no significant relationship between performance in ETM required calculus courses and overall GPA
- Hypothesis 2 – there is no significant relationship between performance in ETM required physics courses and overall GPA
- Hypothesis 3 – there is no significant relationship between performance in an applied solid modeling course and overall GPA
- Hypothesis 4 – there is no significant relationship between performance in an introduction to manufacturing, materials, and processes course and overall GPA
- Hypothesis 5 – there is no significant relationship between performance in an introductory statics course and overall GPA
- Hypothesis 6 – there is no significant relationship between performance in an introductory dynamics course and overall GPA
- Hypothesis 7 – there is no significant relationship between performance in an introductory strengths and properties of materials course and overall GPA

Results

The demographics of the study subjects were 304 males and 21 females earning a 130 credit-hour bachelor's degree in Mechanical Engineering Technology. The median time to graduation for students who maintained full-time enrollment was 9 semesters, and the mean was 9.38 semesters. The median GPA was 2.87, and the mean was 2.93 with a standard deviation of 0.44. The GPAs were nearly normally distributed, as indicated by the probability plot.



Hypothesis 1, there was a significant relationship between performance in ETM required calculus courses and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA ETM Math Grades vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	14.85	14.85	106.88	0.00
Error	289	40.15	0.14		
Total	290	55.00			

Hypothesis 2, there was a significant relationship between performance in ETM required physics courses and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA ETM Physics Grades vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	24.16	24.16	236.79	0.00
Error	297	30.31	0.10		
Total	298	54.47			

Hypothesis 3, there was a significant relationship between performance in an applied solid modeling course and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA Appl Solid Model Grade vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	20.93	20.93	180.39	0.00
Error	310	35.97	0.12		
Total	311	56.90			

Hypothesis 4, there was a significant relationship between performance in an introduction to manufacturing, materials, and processes course and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA Manuf Matl Proc Grades vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	24.20	24.20	214.80	0.00
Error	317	35.72	0.11		
Total	318	59.92			

Hypothesis 5, there was a significant relationship between performance in an introductory statics course and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA Statics Grades vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	14.50	14.50	102.04	0.00
Error	307	43.62	0.14		
Total	308	58.12			

Hypothesis 6, there was a significant relationship between performance in an introductory dynamics course and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA Dynamics Grades vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	17.84	17.84	134.65	0.00
Error	321	42.54	0.13		
Total	322	60.38			

Hypothesis 7, there was a significant relationship between performance in an introductory strengths and properties of materials course and overall GPA at P 0.00 and the hypothesis was rejected.

ANOVA Strength of Matls Grades vs Overall GPA

Source	DF	SS	MS	F	P
Regression	1	21.96	21.96	185.40	0.00
Error	316	37.43	0.12		
Total	317	59.39			

Discussion

There was a significant relationship between the grades in all the required major foundational courses analyzed and the overall GPA of subjects who had completed the MET degree program at Behrend. That was not unexpected because success in these foundational courses is required to complete the program. Although all the relationships were significant, the strength of the relationship was of interest. The analysis was taken further by investigating the R-squared values to find the proportion of variance in the GPAs that could be predicted from the individual courses, and therein were the differences.

As noted in previous work [8], knowledge of certain topics in mathematics is necessary for many engineering technology courses, including statics, dynamics, thermodynamics, heat transfer, and so on, but in an MET curriculum, the introductory level courses in these topics do not all require calculus as a prerequisite. These courses can be taught with techniques that only require trigonometry or algebra. At Behrend, nearly three-quarters of the subjects in this study, 240 of the 325, did not have transfer credit for, or test into, Calculus I when beginning their studies. Only 15% of the subjects, 49 of 325, began their studies with a mathematics course at a lower level than the first required course, Trigonometry and Analytic Geometry. Nearly 20% of the subjects, 62 of 325, had to retake their ETM calculus course. This may delay progress in the major because some courses cannot be enrolled in by students in pre-major status, even if calculus is not a prerequisite for that particular course.

The adjusted R-squared value of Overall GPA vs ETM Math was only 26.74%, which was lower than every other correlation evaluated except Mechanics for Technology: Statics, which was 24.70%.

Overall GPA vs ETM Math		
S	R-sq	R-sq(adj)
0.37	27.00%	26.74%

Overall GPA vs Statics		
S	R-sq	R-sq(adj)
0.38	24.95%	24.70%

The four highest R-squared values were for ETM Physics at 44.17%, Manufacturing Materials and Processes at 40.20%, and nearly equal were Strength and Properties of Materials at 36.78% and Applied Solid Modeling at 36.58%, respectively.

Overall GPA vs ETM Physics		
S	R-sq	R-sq(adj)
0.32	44.36%	44.17%

Overall GPA vs Manuf Matl & Proc		
S	R-sq	R-sq(adj)
0.34	40.39%	40.20%

Overall GPA vs Strength of Matls		
S	R-sq	R-sq(adj)
0.34	36.98%	36.78%

Overall GPA vs App Solid Model		
S	R-sq	R-sq(adj)
0.34	36.78%	36.58%

Based on the previous work [1], [8] and the additional data gathered in this study, the Department is considering changes including removing calculus as an ETM requirement, while retaining it in the curriculum, and instead using courses for ETM that more accurately predict the success of the students. With the ETM calculus courses having a much lower relationship to overall student success, this allows the potential for an innovative change to the program. Technical Calculus and other advanced mathematics courses, including Calculus with Engineering Technology Applications, and Intermediate Calculus and Differential Equations with Applications, would remain in the curriculum as requirements for the major, and would be maintained as prerequisites to certain upper level courses, but would not be a barrier to students entering the MET major.

Physics would be maintained as an ETM requirement, and other courses will be considered to replace calculus for ETM, including Manufacturing Materials and Processes, Strength and Properties of Materials, and Applied Solid Modeling. The materials and processes course is typically taken in the fall semester of the first year and has no prerequisites. Applied solid modeling is usually taken in the spring semester of the first year, and the prerequisite is an introduction to graphics and solid modeling course. The strength of materials course is typically taken in the fall semester of the second year and has prerequisites of statics and trigonometry.

Conclusions

Having an established program in place for students wishing to major in engineering technology or engineering, who do not test into calculus, can help ensure student success. At Behrend, the median time to graduation for MET students who did not start their studies in calculus was 9 semesters, and the mean was 9.38 semesters. For those who started in calculus, the median was also 9 semesters with a slightly lower mean of 9.05 semesters. It is demonstrably possible for students who do not start their mathematics at the level of Calculus I to be successful in an accredited engineering technology program. At Behrend, students in the MET program who started their studies in or had transfer credit for Calculus I were no more likely to graduate in 8 semesters than were students who started at a lower level of math.

To aid students who may initially struggle with their college-level mathematics courses, Behrend has in place an innovative program called the “mathematics slide down policy,” in which students are allowed, until the end of the fourth week of classes, to drop a mathematics class and add its prerequisite. The standard add/drop period is the first week of classes. To complete the slide down, the student must obtain the signatures of the instructor of the initial course, the instructor of the new course, and their academic advisor. The instructor of the new course does not take into consideration the student's performance in the initial class when the final grade is determined. This policy was instituted to help address concerns with pre-major STEM students, including those in engineering and engineering technology, who may initially struggle with college-level mathematics. In MET, this policy is typically implemented by students who start in Calculus with Analytic Geometry and then transfer down to the Trigonometry and Analytic Geometry course. The course the students drop does not count as an attempt and will not appear on their transcript. When there are alternate plans for progress through a major based on a student’s mathematics preparation pre-college, it can be communicated to students that not

starting in calculus, or not being initially successful, should not keep them from pursuing their desired major.

While the calculus courses used for ETM requirements are the same courses that are enrolled in by students in a variety of STEM majors across the campus, the last two courses in the mathematics series for MET majors are for engineering students only: Calculus with Engineering Technology Applications, and Intermediate Calculus & Differential Equations with Applications. Faculty in Engineering, Engineering Technology, and Mathematics at Behrend are currently working towards revising those courses to make them more relevant to enrolled students and potentially improve student success. Changes being discussed include the addition of engineering specific problems/assignments and instruction on the use of specific tools such as Mathcad, Excel, and certain TI calculators that are used across engineering courses to solve mathematics problems.

References

[1] N. E. Study & S. Nozaki. "Performance in Introductory Engineering Graphics Courses as an Indicator of Future Success in a Mechanical Engineering Technology Program (WIP)," *Proceedings of the 2025 ASEE Annual Conference & Exposition*, Montreal, QC. https://peer.asee.org/57036

[2] A. Galbraith, H. A. Schluterman, L. Massey, & B. Crisel. "Exploring the relationship between initial mathematics course in college and engineering graduation rates." *Proceedings of the 2022 ASEE Annual Conference & Exposition,* Minneapolis, Minnesota. https://peer.asee.org/41507

[3] J.B. Main & A. Griffith. "The impact of Math and Science Remedial Education on Engineering Major Choice, Degree Attainment, and Time to Degree." *Proceedings of the 2022 ASEE Annual Conference & Exposition,* Minneapolis, Minnesota. https://peer.asee.org/40864

[4] G.A. Mosher. "Engineering Technology Students: Factors Predicting Success." *Proceedings of the 2018 ASEE Annual Conference & Exposition,* San Antonio, Texas. https://peer.asee.org/31370

[5] C. R. Bego, J. L. Hieb, & P. A. Ralston. "Barriers and bottlenecks in engineering mathematics: Math completion predicts persistence to graduation," *IEEE Frontiers in Education (FIE) Conference*, 2019. 10.1109/FIE43999.2019.9028542

[6] S. Lee, M. C. Harrison, G. Pell, & C. L. Robinson. "Predicting performance of first year engineering students and the importance of assessment tools therein," *Engineering Education*, 3(1), 44–51, 2008. https://doi.org/10.11120/ened.2008.03010044

[7] E. W. Burkholder. "Quantitative Investigation of Preparatory Math Coursework as a Barrier for Degree Attainment in Engineering," *International Journal of Engineering Education* Vol. 39, No. 5, pp. 1286–1296, 2023.

[8] S. Nozaki, & N. E. Study. "Longitudinal assessment of spatial skills development in MET students," *Proceedings of the ASEE Annual Conference & Exposition*, Portland, Oregon. https://peer.asee.org/47752