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An Early Detection of Students Mathematical Competency in Engineering Mathematics Courses

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ABSTRACT

This study aims to identify the mathematical competency of first-year students in engineering mathematics courses at Universiti Kebangsaan Malaysia (UKM). A pre-test was conducted prior to the Vector Calculus class. The test consists of 28 questions on topics such as functions, limits, differentiation, vectors, geometry, and trigonometry. A total of thirty-five students participated in the study. Correlation analysis revealed a weak positive relationship between SPM Additional Mathematics scores and pre-test results (r = 0.215) and a moderate correlation with pre-university grades (r = 0.350), indicating the limited predictive power of high school achievements for university-level readiness. The findings highlight strengths in vector operations and integration but significant weaknesses in trigonometric functions and multivariable calculus. These gaps underscore the need for targeted interventions to support students in bridging the transition from pre-university to advanced engineering mathematics. Early detection of mathematical deficiencies through diagnostic testing can guide the design of remedial programs, enabling educators to address specific areas of difficulty. This study highlights the need to align pre-university curricula with the mathematical requirements of engineering education to help students succeed in their courses. Future research should explore adaptive diagnostic tools for individual learning strategies.

Keywords: Early detection; mathematics competency; engineering mathematics courses; vector calculus; pre-test

INTRODUCTION

Globally, engineering education has encountered growing challenges concerning students' mathematical readiness particularly during the transition from secondary to tertiary education. A significant number of students struggle to meet minimum competency benchmarks in mathematics courses. This issue is more apparent among first year university students and high school pupils where foundational skills in problem-solving and mathematics skills are lacking. Büchele & Feudel (2023) indicates that although curriculum revisions have improved process competences like reasoning and representation, student's ability to conduct symbolic computations has decreased. In engineering, early skills in mathematical domains are an important factor in students' ability to navigate and succeed in complex technical courses. Diagnostic testing has proven to be an effective approach to identify problems and support remedial interventions early. In Malaysia, similar concerns are emerging, particularly among students transitioning from SPM and matriculation systems to university-level courses. This study addresses these gaps by implementing a pretest diagnostic strategy to measuring mathematical ability among first year engineering students, thus providing data driven for curriculum alignment and instructional support.

In recent years, there has been growing concern regarding the decline in mathematical competency among students entering engineering programs at the university level Pepin et al. (2021). Santos et al. (2022) found

engineering freshmen at Wesleyan University-Philippines had limited mastery of essential mathematical concepts from high school. Similarly, Panaoura et al. (2024) observed that students' previous mathematical knowledge significantly influenced their performance in introductory engineering courses. This issue is critical as mathematical proficiency is foundational to engineering fields. It directly impacts students' ability to understand complex engineering concepts and perform technical problem-solving effectively Fernando et al. (2022). Despite the challenging mathematics curriculum at pre-university levels including the Sijil Pelajaran Malaysia (SPM) and pre-university courses, many students encounter difficulties in smoothly transitioning to university-level mathematics (Thoma & Nardi 2018) which provides the basis of their engineering education. This challenge is often attributed to the differences between the learning approaches used at secondary levels which prioritize rote memorization, procedural problem solving and university requirement which require deeper conceptual understanding, critical thinking and the ability to apply mathematical knowledge in complex and real-world engineering contexts. Moreover, students are not exposed to multivariable functions, abstract reasoning, and mathematical modeling during pre-university education for topics such as vector calculus, differential equations and linear algebra which are essential in engineering. This gap not only affects academic achievement but also reduces students' confidence and motivation in tackling mathematical courses.

Research shows that the gap between students' pre-university achievements and their performance in engineering mathematics courses is widening. Several factors may explain this decline, such as a lack of deep understanding of mathematics, too much focus on memorization, and weak problem-solving skills (Nilimaa 2023). Additionally, changes in teaching methods, assessment practices, and increased use of technology in education may have led to superficial learning where students pass examinations without understanding the content Wijaya et al. (2024). To succeed in vector calculus, students need a strong foundation in key areas of mathematics (Thompson & Harel 2021). Basic calculus, including single-variable differentiation and integration is important for understanding more complex concepts.

Students should know the rules of differentiation such as the chain rule, product rule and quotient rule and be able to solve both definite and indefinite integrals. Understanding the link between differentiation and integration as explained by the Fundamental Theorem of Calculus is also essential. In multivariable calculus, students deal with functions of multiple variables and need to understand partial derivatives, limits, and continuity in higher dimensions. Mastering these topics helps them solve real-world engineering problems. Linear algebra is equally important, as students must know vector operations like addition, scalar multiplication, dot products, and cross products. They also need a good understanding of matrices, determinants, and systems of linear equations to solve engineering problems. Besides, geometry and trigonometry are key as well, especially for understanding 3D shapes like planes, curves, and surfaces. Students must be comfortable with trigonometric identities and work with polar, cylindrical, and spherical coordinates to apply math in engineering. Basic knowledge of differential equations can also be helpful as solving ordinary differential equations (ODEs) can deepen their understanding of vector fields, which are important in advanced engineering courses. These mathematical skills are the foundation for learning key concepts in vector calculus, such as vector fields, line and surface integrals, and Fundamental Theorems such as Green's, Stokes', and the Divergence Theorem.

These concepts are crucial for many applications in physics and engineering. Therefore, students need to have a strong mathematics background to make success in advanced engineering courses. A lack of skills in these areas affects a student's success not only in vector calculus but also in other advanced engineering courses like dynamics, fluid mechanics, and thermodynamics, where mathematics skills and student knowledge are essential Faulkner et al. (2020). This gap in competency delays students' academic progress and limits their preparation for entering the engineering field (Boyles & Dabney, 2023). The impact of this issue goes beyond the classroom as engineers depend on mathematics for design, analysis, and innovation. Therefore, identifying mathematical weaknesses early is essential for supporting difficulty students Ardi et al. (2019). By identifying gaps in understanding at the beginning of their university studies, educators can use pretest and create focused support strategies to address specific weaknesses. Vinogradova et al. (2019) highlighted the need to build mathematical competence in engineering education and suggested the use of professional tasks to improve students' motivation, thinking, and reflection. This study examines the mathematical competencies of first-year engineering students at Universiti Kebangsaan Malaysia (UKM) through a pretest conducted before student begin of their vector calculus course. The goal is to identify areas of student's difficulty and provide specific treatment to enhance their success in advanced mathematics courses.

METHODOLOGY

This study involved by 35 first-year students from the Department of Mechanical Engineering at Universiti Kebangsaan Malaysia (UKM). These students were registered in KKKQ1123 *Vector Calculus* course. The course is fundamental for engineering students. Advanced topics covered in the course include partial derivatives, vector functions, line integrals, double and triple integrals, Green's Theorem, Stokes' Theorem, Gauss' Theorem, and basic differentiation and integration of complex functions. A pretest of 28 multi-objective questions were given at the beginning of the course to measure the student's abilities in mathematics.Table 1 shows the questions for each of the topics. These questions covered topics that students have learnt during their pre-university education. The topics assessed included basic functions, limits, differentiation, vectors, integration, geometry, and trigonometry. The questions aimed to assess students' procedural knowledge and their conceptual understanding of these fundamental areas. The pretest was administered during the first week of the semester. Students were given one hour to complete the test.

In addition to the mathematical questions, background information was collected on students' previous academic achievements, specifically their grades in Mathematics and Additional Mathematics during the Sijil Pelajaran Malaysia (SPM) and their pre-university results. The pretest covered several important mathematical topics needed for success in vector calculus. In the area of functions and limits, students were tested on their ability to work with functions, including piecewise functions parametric equations, and one-sided limits. For differentiation, questions focused on the product rule, interpreting derivatives graphically, and applying the chain rule, especially in trigonometric contexts. Students were also tested on vector operations like the dot product and cross product, along with solving problems involving vector quantities and equations of planes. The integration section included questions on definite integrals, integration by parts, and substitution methods, all of which are essential for understanding higher-dimensional calculus. Additionally, students were asked to demonstrate their knowledge of three-dimensional geometry, the use of trigonometric functions, and how to convert between spherical and Euclidean coordinate systems.

TABLE 1. The questions for each of the topics

No Questions	Topics
1	Functions
2	Piecewise Functions
3	Parametric Equations
4	Odd and Even Functions (Trigonometric Functions)
5	Limits (One-Sided Limits)
6	Differentiation (Product Rule)
7	Sequences and Series (Convergence and Divergence)
8	Vectors (Vector Quantities)
9	Dot Product (Vector Operations)
10	Cross Product (Vector Operations)
11	Equation of a Plane
12	Dot Product (Vector Operations)
13	Cross Product (Vector Operations)
14	Equation of a Plane
15	Dot Product (Application in Vectors)
16	Cross Product (Application in Vectors)
17	Determinants (Matrices)
18	Equation of a Plane (Using Normal Vectors)
19	Partial Derivatives (Multivariable Functions)
20	Differentiation (Graphical Interpretation of Derivatives)
21	Chain Rule (Differentiation of Trigonometric Functions)
22	Trigonometric Functions (Properties of Trigonometric Functions)
23	Definite Integrals (Area Under a Curve)
24	Integration by Parts

continue ...

... cont.

25	Substitution Method (Integration)
26	Polynomial Integration
27	Conic Sections
28	Conversion of Coordinates (Spherical and Euclidean Coordinates)

The test scores and students' pre-university grades were converted to Grade Point Average (GPA) format for statistical analysis. The analysis aimed to identify correlations between students' prior mathematical performance (SPM Additional Mathematics and pre-university results) and student pretest results. The analysis also provides insights into the predictive value of previous academic achievement in evaluating students' readiness for university-level mathematics.

The use of Pearson correlation analysis in this study provides an initial understanding of the linear relationship between students past academic performance and their pretest results. Although the correlations provide insightful analysis, it is important to interpret these results within certain limitations. Several factors affect academic success including students' learning environment, instructional styles, exam anxiet, and socio-emotional readiness which are not captured in GPA scores alone. Moreover, the sample size could be improved in future studies by employing Rasch measurement models or structural equation modeling (SEM). These additional analyses could allow for identifying latent traits in students' mathematical abilities and provide a deeper knowledge of their engineering mathematics readiness.

ANALYSIS

All grades Sijil Pelajaran Malaysia and preuniversity were converted into grade point average (GPA). The results of the pretest were also converted into GPA format. Table 2 below shows a correlation studies that were conducted based on correlations between SPM Additional Mathematics scores and pretest results, correlation between pre university scores and pretest results and correlation between SPM Additional Mathematics scores and pre university scores.

TABLE 2. Correlation between SPM Additional Mathematics scores and pretest results, correlation between pre university scores and pretest results and correlation between SPM Additional Mathematics scores and pre university scores

	Additonal Mathematics	Pre-University	Pre-Test
Additonal Mathematics	1		
Pre-University	0.223527117	1	
Pre-Test	0.214799667	0.350395051	1

The correlation coefficient between the SPM Additional Mathematics scores and the Pretest is 0.215. This indicates a weak positive relationship between students' SPM Additional Mathematics performance and their diagnostic test scores. Although there is a slight tendency for students who scored well in SPM Additional Mathematics to perform better on the pretest, the relationship is not strong. This suggests that while the SPM Additional Mathematics results provide some insight into students' mathematical abilities, they may not fully reflect their preparedness for university-level engineering mathematics.

Meanwhile the correlation coefficient between Pre-University grades and the Pretest is 0.350. This represents a moderate positive correlation. It suggests that students' Pre-University results are better predictors of their performance in the pretest compared to their SPM Additional Mathematics scores. Students who achieve higher pre-university grades are more likely to perform better in the pretest. This could be because Pre-University courses often emphasize advanced mathematical concepts that are more aligned with university-level expectations. Further, the correlation coefficient between SPM Additional Mathematics scores and Pre-University results is 0.224. This also indicates a weak positive relationship and suggests that there is some alignment between performance in SPM Additional Mathematics and Pre-University grades. Other factors may influence students' academic achievements during their pre-university studies. These could include differences in curriculum, teaching quality, and the students' overall academic development.

RESULTS AND FINDINGS

The results of the pretest reveal significant variability in students' performance across different mathematical topics. Table 3 presents a detailed breakdown of the percentage of students who answered each question correctly.

TABLE 3. Percentage Student with Correct Answer

No of Questions	Percentage Student with Correct Answer (%)
1	40
2	20
3	51.43
4	0
5	34.29
6	48.57
7	37.14
8	74.29
9	31.43
10	37.14
11	68.57
12	94.29
13	48.57
14	42.86
15	51.43
16	65.71
17	25.71
18	51.43
19	20
20	5.74
21	42.86
22	94.29
23	80
24	57.14
25	74.29
26	60
27	34.29
28	48.57

From the results, it is evident that 94.29% of students answered correctly in topic of dot product and 80% students performed well in definite integrals. However, there were significant weaknesses in other topics such as in trigonometric functions where students answered 0% correctly in odd and even functions, 20% correctly in partial derivatives and 20% correctly in piecewise functions. These results suggest that while students may have a good grasp of basic vector operations and integration, they struggle with more abstract concepts that require a deeper conceptual understanding, such as trigonometry and multivariable calculus.

These findings hold strong implications for both teaching strategies and policy-level decisions. Firstly, they recommend for the inclusion of diagnostic screening in the early weeks of first-year engineering programs as part of a larger academic support framework. Secondly, they highlight the need for a curriculum redesign in pre-university programs to ensure better transitions into university mathematics. Higher-order thinking skills, visual problem-solving and multivariable analysis applied at earlier stages may help students to be equipped for the demands of engineering courses. Universities could also consider implementing bridging modules tailored to students' diagnostic profiles, thereby promoting more equitable learning outcomes.

In conclusion, this study not only highlights important deficiencies in the mathematical skills of first-year engineering students but also explores the need for early intervention strategies. This diagnostic assessment enables institutions to adopt more responsive and flexible teaching strategies. Future initiatives could focus on developing intelligent diagnostic platforms. This potentially improves national competency in engineering education. As Malaysia aims to compete globally in science and technology areas, ensuring mathematical readiness at the university level becomes a strategic educational priority.

DISCUSSION

The findings of this study provide valuable insights into the mathematical readiness of first-year engineering students and the importance of early pretests in identifying areas for intervention. The weak correlation between SPM Additional Mathematics scores and pretest performance indicates that high school results provide some insight into students' mathematical abilities. However, these results did not fully reflect students' preparedness for the specific challenges of university-level mathematics (Gregorio et al., 2019). On the other hand, the stronger correlation between pre-university results and diagnostic test performance suggests that pre-university education, particularly in matriculation and foundation programs, plays a more significant role in preparing students for advanced mathematical concepts in engineering. The pretest's performance across different topics highlights the necessity in focusing teaching methods to address student's weakness. For instance, students had difficulties with trigonometric functions, multivariable calculus, and partial derivatives, indicating gaps in their understanding of these mathematical concepts even though they performed well in areas of vector operations and integration. These gaps are particularly important because these topics form the

foundation for more advanced engineering courses. The results suggest that past academic performance SPM Additional Mathematics scores provide some insight. However, it may not be enough to fully measure students' readiness for university-level math. Therefore, pretests can play a critical role. By identifying students' strengths and weaknesses early in the academic year, educators can use this information to provide targeted support, address knowledge gaps, and ensure students are better prepared for advanced courses. The study also highlights the need to align pre-university courses with the requirements of engineering programs at university. Topics such as vector calculus, multivariable calculus, and advanced trigonometry are critical for student success in higher-level engineering courses, yet many students enter university without a strong understanding of these concepts. Universities and pre-university institutions should collaborate to make sure students are well-prepared for the transition to university-level mathematics. This collaboration should include curriculum alignment, group curriculum mapping workshops, and shared assessment strategies that reflect the cognitive and problem-solving needs of tertiary-level engineering programs. Pre-university instructors should be made aware of the expectations in first-year engineering mathematics courses, while university lecturers can benefit from understanding students' prior learning experiences and limitations. Bridging programs, early intervention modules, and group diagnostic frameworks can be developed to ensure consistency in learning objectives and assessment standards. Cooperative professional development programs can also promote alignment in pedagogy especially in helping student to enhance higher-order thinking skills, visualization techniques, and application of mathematical reasoning to real-world engineering problems. Moreover, establishing formal partnerships between educational institutions may facilitate data sharing, continuous feedback loops and keep track of students' academic progress. Such systematic collaboration ensures that students are not only academically equipped but also emotionally and strategically prepared for the mathematical nature of engineering education.

CONCLUSION

This study demonstrates the value of early pretest in detecting mathematical competency gaps among first-year engineering students. The weak correlation between high school mathematics performance and university-level preparedness as well as the variability in pretest results across different mathematical topics indicates that early detection and intervention are essential for student success in engineering courses. By identifying students' weaknesses at the start of the academic year, educators can provide targeted support to help students build the necessary foundation in mathematics Tan et al. (2018). Future research should explore the development of more comprehensive diagnostic tools that assess not only procedural knowledge but also students' conceptual understanding of key mathematical concepts (Brendefeur et al., 2018). Such tools should be designed to identify specific misconceptions, cognitive gaps and the depth of mathematical reasoning required in engineering disciplines. Incorporating real-time analytics and feedback mechanisms could further enhance their effectiveness in guiding instructional decisions. In addition, institutions should implement adaptive learning platforms that provide personalized learning pathways based on pretest outcomes, such as those utilizing artificial intelligence and machine learning (Soler Costa et al., 2019). These intelligent systems can dynamically adjust learning content, pace and difficulty according to each student's competency level. They also enable timely intervention for at-risk learners and foster a sense of ownership in learning. These platforms can increase student engagement, learning effectiveness, and satisfaction (Hinkle et al., 2020), while also contributing to more equitable access to academic support. Ultimately, the combination of diagnostic tools with adaptive technologies holds significant potential to improve long-term student achievement and preparedness for complex mathematical applications in engineering careers.

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DECLARATION OF COMPETING INTEREST

None

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