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Literature Review on the Teaching Engineering Mathematics: Issues and Solutions for Student Engagement

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Abstract

Engineering mathematics is essential for fostering analytical and problem-solving abilities in engineering education, especially in Malaysia, where it plays a crucial role in the nation's technical and industrial ambitions. Nevertheless, students encounter substantial obstacles such as the need to strike a balance between grasping abstract concepts and acquiring practical skills, surmounting feelings of apprehension about mathematics, actively participating in crowded classrooms, and adapting to the demands of online education and self-directed study. This paper examines the difficulties and suggests remedies, with a focus on incorporating active learning methods, creating supportive learning environments, and using digital resources to improve student involvement and understanding. The study emphasizes the significance of visualizing abstract mathematical ideas and establishing connections with practical engineering applications. These strategies are important to maintain the sustainable development of engineering education. By using these strategies, instructors may enhance pupils' readiness for prosperous engineering jobs, guaranteeing that they grasp mathematical ideas, and possess the ability to apply them proficiently in real-world situations.

Keywords

Engineering mathematics, Engineering education, Sustainable development education

Introduction

Engineering mathematics is a fundamental topic in engineering education, crucial for cultivating the analytical and problem-solving abilities necessary in the discipline (Litzinger et al., 2011, Van et al., 2020). Engineering education in Malaysia has been gaining significance as the government aims to position itself as a center for technical advancement and industrial expansion (Foo, 2013; Idris et al., 2023). Malaysian universities have broadened their engineering programs to include many specializations that demand a thorough understanding of mathematics, with the aim of creating graduates who can satisfy international engineering standards (Isa et al., 2021).

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Nevertheless, the instruction and acquisition of mathematics in engineering settings can pose substantial difficulties. Students sometimes face difficulties in comprehending the abstract and intricate nature of mathematical ideas (Flegg et al., 2012; Montfort et al., 2009), which are essential components of engineering disciplines like electrical, civil, and mechanical engineering. Conventional teaching methods, known as "chalk-and-talk," have historically been the primary approach to instruction. In this method, teachers depend on delivering lectures and using blackboard demonstrations to communicate mathematical concepts. Although this strategy has its advantages, it frequently falls short of completely engaging pupils, especially those who need more interactive and hands-on learning opportunities.

The emergence of digital technology has brought out new opportunities for teaching and learning, resulting in an increasing inclination towards integrating online learning aids in engineering mathematics education (Borba et al., 2016; Engelbrecht & Borba, 2024; Krishnan & Foo, 2024; Liu et al., 2024). These tools, which vary from basic educational software to extensive online platforms, provide an alternative to the traditional classroom environment, granting students adaptable learning options and individualized feedback. Although online learning in mathematics education has potential advantages, it also presents obstacles (Irfan et al., 2020). Both students and instructors have challenges related to accessibility, the efficacy of online tools in explaining intricate mathematical ideas, and the requirement for technological assistance.

This empirical paper analyzes the primary obstacles that students face when studying engineering mathematics and suggests potential solutions. The study provides valuable insights into the impact of online learning on students' involvement and understanding of mathematics, establishing a basis for examining broader trends and methodologies in engineering mathematics education.

Challenges in Teaching Engineering Mathematics

Mathematics necessitates a profound comprehension of theoretical ideas and a solid grounding in real-world implementation (Kaiser, 2020). Teaching the topic, especially in the engineering field, sometimes presents various obstacles due to the need to fulfill both requirements simultaneously.

Conceptual understanding and procedural knowledge

Engineering students often have substantial difficulty finding a balance between their grasp of abstract concepts and their practical skills (Streveler et al., 2008). Although individuals may demonstrate proficiency in applying formulae in calculus or executing algorithms in linear algebra, their procedural knowledge typically lacks profound understanding. If pupils do not have a solid understanding of the fundamental principles, they may struggle when confronted with unfamiliar issues that demand analytical thinking beyond just memorization (Richland et al., 2012). For instance, a student may possess the ability to solve a conventional differential equation by applying the techniques they have acquired. However, when confronted with a practical engineering challenge that necessitates modifying those equations to suit a particular situation, they can encounter difficulties. The lack of comprehension about the underlying reasons behind mathematical concepts might impede individuals from effectively using them in engineering design or analysis. This, in turn, can have a negative impact on their performance in academic and professional contexts.

Subject Anxiety

Mathematics anxiety is a widely studied occurrence that has a substantial influence on students' academic achievement, especially in the field of engineering (Vitasari et al., 2010; Luttenberger et. al., 2018). This anxiety manifests as a fear or unease when faced with mathematical activities, frequently leading to avoidance and decreased performance. The demand to comprehend intricate topics inside a restricted period intensifies this worry, establishing a harmful loop where pupils' apprehension of failing further obstructs their capacity to study efficiently. For example, an engineering student experiencing anxiety about mathematics may encounter difficulties in fundamental disciplines such as calculus or statistics, which are essential for comprehending more complex topics like signal processing or thermodynamics. This worry can also impact their self-assurance, leading to a higher probability of withdrawing from class discussions, avoiding asking for assistance, and finally, achieving subpar results in tests and assignments.

Large number of students in a single class

Teaching engineering mathematics to many students is a difficult task, especially when using traditional in-person teaching techniques. In a conventional, spacious lecture hall, there is minimal individual attention, and the interaction between the lecturer and students is generally restricted to unidirectional communication (French & Kennedy, 2017). This configuration can result in passive learning, wherein pupils are more inclined to disengage and less inclined to recall intricate mathematical concepts. For instance, in a sizable calculus class, a professor may not have the chance to attend to individual students' inquiries or offer tailored comments, leading to several pupils experiencing confusion or detachment from the subject matter. The absence of active participation not only reduces the quality of the learning process but also leads to decreased retention rates and a less comprehensive grasp of fundamental engineering principles.

The transition from conventional face-to-face to online learning

The shift towards online learning in engineering education, while offering significant flexibility, also introduces a unique set of challenges. Smith and Ferguson (2005) noted that compared to other subjects, online mathematics courses frequently have higher attrition rates. This is partly due to the inherent difficulties in using mathematical symbols and notation in an online environment, where traditional paper-and-pencil methods are not easily replicated. For instance, students may find it cumbersome to input complex equations into a digital platform or may struggle to interpret mathematical expressions presented on a screen. Additionally, the lack of immediate feedback and face-to-face interaction can make it harder for students to stay motivated and engaged. In real-world scenarios, such as when an engineering student needs to collaborate with peers on solving a problem set via an online forum, the limitations of digital tools can become apparent, potentially leading to frustration and disengagement.

The transition from spoon-feeding to independent learning

Engineering students undergo a notable transformation in their learning style when they go from secondary school to university, transitioning from a passive learning strategy where information is provided to them to a more autonomous and self-directed learning model (Al-Saadi, 2011). During secondary school, students are often given comprehensive assistance and detailed instructions to successfully complete tasks and grasp complex ideas. Teachers diligently oversee the progress of pupils and often offer reminders and assistance to ensure that they remain on schedule. However, in the context of university education, especially in engineering degrees, students are required to assume responsibility for their own learning. This transition can be disorienting; students who are accustomed to receiving guidance for every task may have difficulties when they must autonomously organize their study routines, search for materials, and evaluate their own progress.

For instance, a mathematics instructor in secondary school may guide pupils systematically through every instance of a specific problem type, checking comprehension of each step before proceeding. Conversely, a university lecturer may present the identical content inside a solitary lecture, anticipating students to peruse the lecture notes, independently solve practice questions, and request assistance only when needed. Students are needed to demonstrate increased levels of self-discipline, time management, and critical thinking throughout this shift. The volume of assignments and the complexity of the material may overwhelm those who are unable to adjust, which could make it difficult for them to succeed in all facets of their engineering education, not just mathematics. The significance of cultivating self-directed learning abilities at an early stage is emphasized by this change, since they are essential for achieving success in the rigorous and rapidly evolving setting of engineering programs at the university level.

Difficulty in visualizing engineering mathematics theories and relating them to real-world applications

Engineering mathematics frequently includes abstract notions and intricate theories that might provide challenges for students in terms of visualization and establishing connections with real-world applications (DeSutter & Stieff, 2017). Unlike areas that are more tactile, where the practical ramifications of an idea may be easily viewed, the mathematical underpinnings of engineering are typically concealed by layers of abstraction. For example, being good at understanding differential equations, vector calculus, or Fourier transforms requires being able to mentally picture waveforms, multidimensional spaces, and other abstract structures.

The lack of ability to visualize might result in difficulties in understanding the practical applications of these mathematical ideas in engineering situations (Kohen et al., 2022; Streveler et al., 2008). For instance, students may acquire the mathematical algorithm for solving a differential equation without attaining a complete comprehension of how that equation represents the dynamics of a physical system, such as the heat conduction in a material or the vibrations of a suspension bridge. The disparity between theoretical mathematical concepts and their actual implementation can lead to a shallow comprehension of the subject matter, wherein pupils can execute computations but encounter difficulty perceiving the pertinence or importance of the outcomes.

To narrow this disparity, it is imperative for engineering education to integrate additional visual aids, simulations, and real-world illustrations that showcase the application of mathematical principles in engineering practice (DeSutter & Stieff, 2017). By utilizing software tools such as MATLAB or Simulink, students can visually see how differential equations elucidate the dynamic behavior of systems and observe the direct consequences of altering variables. In addition, case studies that show how mathematical ideas are used in real-life engineering projects can help students understand how the math they learning are useful. For example, they could be used to create electrical circuits, study how fluids move through pipelines, or evaluate building structures. By explicitly establishing these links, instructors may assist students in cultivating a more profound and cohesive comprehension of engineering mathematics and its pivotal function in resolving practical issues.

Solutions to Enhance Learning Outcomes

Addressing the challenges of learning engineering mathematics requires a multifaceted approach that combines innovative teaching methods, supportive learning environments, and the integration of technology (Figure 1.1). Students often struggle with balancing conceptual understanding and procedural knowledge, managing mathematics anxiety, and staying engaged in large classes. The transition to online learning and the shift from spoon-fed secondary education to independent university study also present significant hurdles. Moreover, visualizing abstract mathematical theories and relating them to real-world engineering applications can be particularly daunting. To overcome these obstacles, educators can implement active learning techniques, use digital tools to enhance engagement, and provide resources that support independent learning. By creating a more interactive and supportive educational environment, these solutions not only help students grasp complex mathematical concepts but also prepare them to apply these principles effectively in their future engineering careers.

Enhancing conceptual understanding alongside procedural knowledge

Achieving a balance between conceptual comprehension and procedural expertise increases the understanding of the concepts and knowledge. Educators have the option to employ a range of tactics that prioritize the rationale behind the methods used. A successful strategy involves the utilization of active learning methodologies, such as problem-based learning (PBL) or inquiry-based learning (IBL) (Rafiq et al., 2023). PBL involves the presentation of authentic engineering issues to students, which necessitates the application of mathematical principles in innovative and novel manners. This not only strengthens their ability to follow a set of steps but also enhances their comprehension of the fundamental concepts. For example, in the study of differential equations, students may be assigned the task of creating a mathematical model for a physical system, such as the cooling of a building. In this work, they are required to determine the appropriate equations to use and justify their choices. This prompts children to engage in critical thinking on the correlations between mathematics and physical occurrences.

An alternative strategy involves integrating conceptual inquiries and dialogues into the curriculum, wherein students are prompted to elucidate the rationale underlying their approaches. For instance, following the resolution of a calculus issue, students may be prompted to articulate how the derivative they calculated corresponds to the tangible rate of transformation in each system. Through consistent participation in these introspective exercises, students may cultivate a more comprehensive comprehension of the principles that form the basis of the methods they employ.

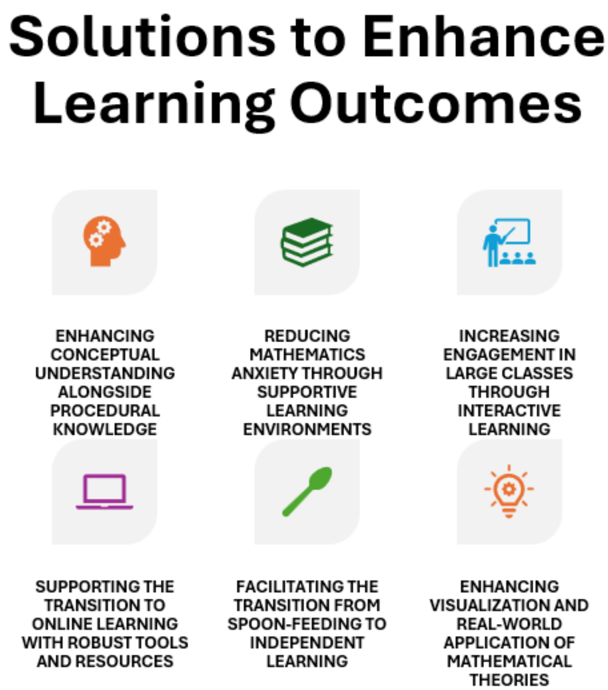

Figure 1.1 Multifaceted solutions to improve students' performance in engineering mathematics

Reducing mathematics anxiety through supportive learning environments

Alleviating mathematics anxiety is very important for the students in learning mathematics in engineering. It is crucial to establish a nurturing educational setting that fosters students' ability to approach mathematics with assurance. An effective approach to doing this is by employing formative evaluations that offer frequent, low-risk feedback (Hansen & Ringdal, 2018). This enables students to promptly see their areas of deficiency and seek assistance without the burden of high-stakes examinations. Incorporating mindfulness and stress-reduction practices in the classroom can assist pupils in effectively coping with anxiety. For example, engaging in short mindfulness exercises before a mathematics exam or a difficult problem-solving session can effectively reduce anxiety and enhance concentration.

Another efficacious approach is to establish mathematical support centers or peer tutoring programs, providing kids with individualized assistance in a less daunting environment. These programs can provide significant advantages for students who may experience excessive anxiety when it comes to asking questions in a large class. To decrease the negative perception of mathematics anxiety and promote greater student involvement, educators can normalize the utilization of these tools and emphasize the positive aspect of requesting assistance.

Increasing Engagement in large classes through interactive learning

Instructors can address the issue of low student involvement in large engineering mathematics classrooms by using technology and implementing active learning strategies to enhance the interactive nature of the learning process (Nguyen et al., 2021). For instance, the use of clickers or mobile applications that enable students to promptly answer questions can enhance engagement, even in a sizable lecture hall. Providing fast feedback not only maintains students' interest but also allows the instructor to assess comprehension and adapt the lesson's speed accordingly.

Flipped classroom models are an additional and efficient method to increase engagement (Gilboy et al., 2015). A flipped classroom is a teaching method where students are assigned pre-recorded lectures or reading materials to review before attending class. This approach enables class time to be focused on engaging activities like collaborative problem-solving, debates, or case studies. This technique promotes active engagement and enables the teacher to efficiently handle specific inquiries and misunderstandings. For example, in a sizable linear algebra course, students may see a recorded lecture on matrix transformations outside of class and subsequently collaborate in groups to solve intricate problems during class time, with the teacher offering assistance and evaluation.

Supporting the transition to online learning with robust tools and resources

To overcome the difficulties related to online learning, especially in the field of mathematics, it is crucial to furnish students with powerful digital tools and resources that can imitate the conventional learning experience. Platforms such as WebAssign or MyMathLab provide functionalities that enable students to effortlessly input and modify intricate mathematical symbols. These systems frequently incorporate interactive lessons and provide immediate feedback on tasks, enabling students to learn and rectify errors in real-time.

Furthermore, including synchronous online sessions, where students can engage with the teacher and their classmates in real-time, helps mitigate the sense of isolation that is occasionally experienced during online learning. Throughout these sessions, educators have the ability to utilize virtual whiteboards to collaboratively solve problems, while students have the opportunity to inquire about any uncertainties, mirroring the experience of a conventional classroom. In addition, providing online office hours or discussion forums where students may submit inquiries and receive prompt replies can provide the continuous assistance necessary for their success in an online setting.

Facilitating the transition from spoon-feeding to independent learning

In order to facilitate the shift from a structured educational setting in secondary school to the self-directed learning environment of university, it is important for educators to prioritize the early development of students' self-regulation abilities. Expanding the level of self-governance in educational assignments is a method for achieving this (Khusainova et al., 2016). For example, during the initial year of an engineering school, teachers may initially provide more structured exercises with detailed instructions but gradually transition to assignments that demand students to develop their own strategies and answers.

Participating in workshops or seminars that focus on time management, study skills, and critical thinking may be quite beneficial for students in adjusting to the challenges of independent learning. In addition, offering organized chances for self-evaluation, such as through the use of reflective diaries or learning portfolios, can motivate students to assume responsibility for their own learning journey. These tools enable pupils to monitor their advancement, establish objectives, and contemplate the techniques that yield the most favorable outcomes, promoting a mentality of ongoing enhancement and lifetime education.

Enhancing visualization and real-world application of mathematical theories

In order to assist students in overcoming the challenge of comprehending engineering mathematics theories and connecting them to practical situations, educators might incorporate a greater number of visual and experiential learning resources into the curriculum (Krishnan & Foo, 2024). Software like MATLAB, Mathematica, or GeoGebra enables the creation of dynamic visualizations of mathematical topics. This allows students to control variables and view the resulting consequences in real-time. For example, students who are learning about Fourier transforms might use MATLAB to visually represent the decomposition of various signals into their frequency components. This helps establish a concrete connection between the theoretical mathematical process and its real-world application in signal processing.

In addition, the inclusion of more practical tasks that require the use of mathematical principles to solve real-life engineering challenges can enhance the comprehensibility of these ideas (Geiger et al., 2018). For instance, a project may entail the creation of a basic electrical circuit and the utilization of differential equations to represent the progression of current over a period of time. By establishing a connection between abstract mathematical concepts and a tangible physical system that can be constructed and experimented with, students are more inclined to cultivate a profound and instinctive comprehension of the subject matter.

For instance, a civil engineer may illustrate a case study on the structural analysis of a bridge, elucidating the indispensability of principles derived from linear algebra and calculus in guaranteeing the safety and stability of the design. This not only strengthens the practical significance of engineering mathematics but also motivates students by demonstrating the tangible effects of the ideas they are learning.

Conclusions

Engineering mathematics plays a crucial role in engineering education, particularly in Malaysia. However, students have difficulties in achieving a balance between conceptual comprehension and procedural expertise, dealing with mathematical anxiety, and adjusting to online learning. This analysis analyses the challenges and proposes remedies, such as active learning, digital tools, and supportive settings, to improve student involvement and understanding. Furthermore, it underscores the need to conceptualize mathematical principles and connecting them to practical engineering scenarios. Using these approaches, educators may enhance students' comprehension of mathematics, therefore equipping them with the necessary skills for proficient problem-solving in their engineering professions.

Future research should compare teaching methods like PBL, IBL, and flipped classrooms to find the best approaches for different students. It should also examine how digital tools affect online learning, track the development of self-directed learning, and explore visualization techniques for understanding abstract concepts. Additionally, research should investigate strategies for reducing math anxiety online, examine the influence of cultural factors on math learning, and explore ways to integrate ethics and social responsibility into engineering mathematics education.

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