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Impact of socio-economic background of the students on the integration of mathematics Ideas into the learning of physical electronics course

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Abstract

Background: The socio-economic background of students plays an important role in shaping their mathematics skills, especially when combining mathematical ideas with learning physical electronics. However, many engineering programs do not consider students' earlier school experiences when they are admitted. Factors like family background, the type of school they went to, and their age are some reasons why it is difficult to connect mathematics to their learning in physical electronics.
Aim: This research aims to study how the socio-economic background of students affects their academic performance when they bring mathematical ideas into physical electronics education.
Method: The study focused on university students taking a physical electronics course in South Africa. A mixed-method approach was used, including semi-structured surveys and interviews, to collect students' opinions about combining mathematics with physical electronics.
Results: The results show that students' socio-economic backgrounds affect how well they can use mathematics in their learning. The findings include: 1) Students had different levels of preparation in mathematics and physics; 2) Performance differences were found between students from rural and urban schools, 3) Those with basic knowledge of mathematics and physics performed better when combining these concepts with physical electronics.
Conclusion: This study found that connecting mathematics to physical electronics helps students understand concepts better. It also introduces a model called the Socio-Economic Based Practical Reward Mathematics Integrative Model (SEB-PRMIM), which is designed to reduce the effects of socio-economic differences and improve mathematics integration in engineering education.

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INTRODUCTION

The integration of mathematics among engineering students remains a reliable tool for blending theoretical mathematics with real-world engineering applications. However, consistency in mathematics integration among engineering students remains a significant issue (Ríordáin et al., 2015). This inconsistency is often linked to students' socio-economic background and other related factors. Various researchers have highlighted that socio-economic status plays a vital role in learning mathematics in an engineering context (Bayat et al., 2014; Jeevarathinam et al., 2023). Despite its importance, previous research has not extensively explored the role of socio-economic status in mathematics integration within engineering education. This highlights the need for further exploration of the socio-economic factors affecting mathematics integration. Factors such as age, schools attended, and the environment (rural or urban) significantly influence students' ability to integrate mathematics into their learning (Vadivel et al., 2023). For instance, high school students within certain age brackets often struggle with mathematics-related courses, which can impact their performance in engineering education. Overlooking these socio-economic factors can negatively

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affect students' academic achievements (Jeevarathinam et al., 2023; Vadivel et al., 2023; Valero et al., 2015). Therefore, addressing these challenges is crucial to improve mathematics integration.

Numerous studies underscore the influence of socio-economic factors on academic performance, but most focus on general academic success rather than subject-specific integration. Previous studies by Cansız et al. (2019), Ersan & Rodriguez (2020), Hascoët et al. (2020), Hasibuan et al. (2022), Kang & Cogan (2022), Lee (2023), Price (2022), Tomaszewski et al. (2024), Wang et al. (2020), and Zhang et al. (2023) points to variables such as age, school type, and parental background as notable contributors to students' academic outcomes. Nonetheless, a gap remains regarding the impact of socioeconomic status on students' capacity to apply mathematical principles within physical electronics—a domain where this integration is essential. Additionally, while some literature (Fateel et al., 2021; Jeong & González-Gómez, 2021; Ji & Li, 2023; Joshi et al., 2022; Shala & Latifi, 2021; Wang et al., 2020; Zeng, 2023) acknowledges the role of academic background in mathematics comprehension, few studies focus specifically on the socio-economic influences in engineering contexts. Thus, there is a need to investigate how socio-economic background shapes students' abilities to integrate mathematics within engineering coursework, particularly in physical electronics. Addressing this gap will provide valuable insights for curriculum development and support strategies.

Electronics engineering is an interdisciplinary field aimed at designing electrical devices to solve current and future challenges. For example, advancements in artificial intelligence (AI) have enhanced the design of electronic devices, including tools for engineering education (Adeyeye & Akanbi, 2024). Mathematics topics such as algebra, differential equations, calculus, and vectors are integrated into physical electronics to equip students with skills necessary for workplace applications (Brand, 2020). These interdisciplinary connections underscore the importance of integrating mathematics into engineering education. Previous findings indicate that engineering students use various mathematics concepts, including calculus, algebra, differentiation, and integration, when studying physical electronics (Fasinu, 2021). However, the success of this integration is influenced by socio-economic factors such as age and school attended. Advanced mathematical topics, like vectors, Poisson processes, Gaussian theory, and queueing theory, are essential in both mathematics and physical electronics modules (Fasinu et al., 2023). Recognizing these relationships can optimize the learning process for engineering students.

Several researchers emphasize the need to redesign science and technology education curricula to meet the increasing demand for integrating mathematics with physical electronics. For example, trigonometry plays a crucial role in engineering tasks such as antenna installation (Balanis, 2016). However, Shimizu and Vithal (2023) and Brand (2020) argue that merely presenting mathematical concepts in school curricula is not sufficient. There must be consistent efforts to connect these concepts with real-world engineering applications to ensure students fully understand their practical uses. Integrating mathematics with other disciplines, such as physics, can make teaching and learning more effective. By showing students how these subjects are connected, educators can help them grasp the relevance of mathematics in solving engineering problems. This approach can also enhance students' problem-solving skills and prepare them for workplace challenges. Furthermore, aligning the curriculum with real-world engineering needs can prevent redundancy, as many topics in mathematics and physical electronics overlap (CAES, 2020). Advanced mathematical tools, such as differential equations, vectors, and Gaussian theory, are integral to designing modern engineering systems. These tools are frequently used in both mathematics and physical electronics modules, demonstrating the importance of an interdisciplinary approach. Therefore, restructuring the curriculum to emphasize these connections is vital for preparing students for the demands of the engineering industry.

Despite its importance, many engineering students face difficulties in integrating mathematics into engineering topics. One key reason for this challenge is socio-economic disparities that shape their early educational experiences. For example, students from rural primary schools often have limited access to quality mathematics education, which creates a gap in their foundational skills (Jeevarathinam et al., 2023). Similarly, parental literacy levels influence the level of support students receive at home, further affecting their academic performance (Brand, 2020). Age is another critical factor. Younger students may lack the maturity to fully grasp abstract mathematical concepts, while older students may face challenges in adapting to advanced topics due to gaps in prior knowledge. Additionally, students' interest in mathematics can be heavily influenced by their socio-economic background. For instance, students from low-income families may prioritize immediate economic needs over academic pursuits, limiting their motivation to engage with complex subjects like mathematics.

These socio-economic factors collectively impact students' ability to integrate mathematics into engineering education. For example, a lack of exposure to advanced mathematical tools, such as differential calculus or Gaussian theory, can hinder their understanding of physical electronics concepts. Addressing these disparities requires targeted interventions, such as supplemental mathematics programs for students from disadvantaged backgrounds and increased access to educational resources in rural areas. By tackling these socio-economic challenges, educators and policymakers can create a more equitable learning environment that supports all students in mastering mathematics integration. This is essential for improving learning outcomes and ensuring that engineering graduates are well-prepared for the demands of the modern workforce. This study investigates the impact of students' socio-economic background on the integration of mathematical ideas into physical electronics education. To address the identified gap, the study is guided by the following research questions:

1. What are the socio-economic factors that influence undergraduate engineering students' ability to integrate mathematics into physical electronics?
2. Do undergraduate engineering students integrate their mathematical ideas into physical electronics learning? If so, what are the benefits of mathematics integration for these students?

LITERATURE REVIEW

2.1 Meaning and the Role of mathematics integration in engineering curriculum

Integrated STEM education has been broadly defined by researchers such as Pepin et al. (2021), Ye et al. (2023), Roehrig (2021), Kelley and Knowles (2016), and Moore et al. (2014). For instance, Moore et al. (2014) describe it as "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (p. 38). However, Kurt and Pehlivan (2013) highlight challenges in implementing curriculum integration, particularly due to uncertainties surrounding traditional teaching methods and approaches in mathematics and science. Similarly, Kelley and Knowles (2016) emphasize that integration serves as a structural framework necessary for aligning lesson plans around a central theme across multiple disciplines. Roehrig (2021) further explains curriculum integration as a blend of multidisciplinary, interdisciplinary, and transdisciplinary approaches, where subjects are combined to achieve a unified goal. This process involves merging previously distinct components or embedding one element into a broader framework while maintaining the relationships between separately taught elements. Additionally, Fasinu and Alant (2023) argue that curriculum integration fosters the alignment of various skills and concepts. In this context, adopting multi-, inter-, and transdisciplinary strategies can enhance learners' conceptual understanding and encourage greater engagement both within and beyond the classroom.

In the literature, curriculum integration appears in various forms and models, each with distinct characteristics and approaches. This section clarifies five key forms of integration to address potential confusion. First, the shared model views the engineering curriculum as a means to unify two or more disciplines through overlapping content. Second, the thematic model conceptualizes the curriculum as a single discipline, facilitating the departmental blending of ideas. Third, the integrated subject approach portrays the curriculum as a kaleidoscope, merging interdisciplinary topics through shared concepts and designs, often involving the integration of more than two disciplines. Fourth, the cross-curricular or threaded model envisions the curriculum as a magnifying glass for exploring overarching ideas, enabling the connection of skills across disciplines. This model fosters networking as cross-disciplinary integration evolves. Lastly, the interdisciplinary model focuses on examining shared problems, topics, issues, and themes across two or more disciplines, employing robust integration strategies. This study emphasizes the integration of mathematics and physical electronics, highlighting the role of mathematics in enhancing engineering students' understanding of physical electronics (Fasinu & Alant, 2023). These various models demonstrate the diverse possibilities of curriculum integration, underscoring its potential to create meaningful connections between disciplines and foster holistic learning experiences.

The continued neglect of teachers by policymakers in curriculum development, particularly in mathematics-related courses, has led to teacher apathy, characterized by partial commitment to integrating mathematics with science curricula. Butman (as cited in Kurt & Pehlivan, 2013) emphasizes that many teachers still struggle to effectively connect mathematics and science in their teaching, which remains a significant challenge in STEM education. Similarly, Kiray et al. (2008) highlight that numerous teachers lack a clear understanding of the pedagogical rationale behind integration, perceiving it as an additional burden. This perception further diminishes their dedication to the teaching and learning process, ultimately hindering the successful implementation of integrated curricula.

A review of the literature on curriculum integration reveals that some mathematics and science teachers lack awareness of the critical role mathematics plays in science and technology, leading them to overlook the importance of integrating mathematics into these subjects (Butuiner & Uzun, 2011). However, research indicates that a significant proportion of pre-service teachers and engineering students possess a general understanding of the concept of integration. For instance, one study found that 93.3% of students demonstrated an understanding of integration, while 6.7% struggled to apply mathematical concepts in their learning. Unfortunately, many teachers lack the confidence to present these concepts effectively, often abandoning integration altogether in their teaching (Frykholm & Glasson, 2005). Similarly, Pant (2017) observed that many teachers were hesitant to integrate subjects due to a lack of confidence. Conversely, Kurt and Pehlivan (2013) noted that while some teachers were eager to implement an integrated curriculum, they lacked the necessary strategies and approaches to do so effectively. Even when teachers possessed strong content knowledge and pedagogical content knowledge, gaps in implementation strategies persisted (Suh et al., 2021). Sitopu et al. (2024) affirm that curriculum integration is more successful when teachers have the requisite knowledge and skills for its implementation. In response, it has been suggested that both in-service and pre-service teacher training programs include workshops and information sessions on curriculum integration (Meisel, 2005). This approach aims to equip teachers with the tools and understanding needed to navigate and implement integrative curricula. Additionally, Newell advocates for curricula that challenge teachers to step out of their comfort zones by engaging in practical, experiential teaching practices, particularly in mathematics-related courses, rather than relying on rote memorization (Pant, 2017). In conclusion, addressing the challenges of curriculum integration requires a multifaceted approach, including professional development, curriculum reform, and strategic support, to empower teachers with the confidence, knowledge, and tools necessary to effectively integrate subjects and enhance student learning outcomes.

The objective of interdisciplinary curriculum integration is to foster a mindset that encourages open access to knowledge while honoring its diversity and enabling a sound understanding to address emerging ideas (LasFever, 2008). Since individuals react differently to learning, effective interdisciplinary integration can only occur when teachers can independently construct knowledge and ideas—a capability achievable through comprehensive educational training (LasFever, 2008). Ríordáin et al. (2015) emphasize the importance of designing teacher education programs that equip educators with firsthand experience in blending or fusing related concepts during the teaching process. Similarly, Lattuca (2001) argues that an integrative critique should explore how disciplinary methods, theories, and perspectives compare and complement one another. This requires teachers to possess a deep understanding of their respective disciplines and fundamental knowledge of integration. According to Repko and Szostak (2016), the integrative process involves synthesizing students' knowledge with discipline-based insights, forging common ground, and arriving at interdisciplinary solutions or perspectives. In conclusion, appropriate teacher education is essential to ensure that educators are adequately prepared to navigate the complexities of interdisciplinary integration, enabling them to deliver meaningful and cohesive learning experiences for their students.

2.2 Benefits of Mathematics Integration and Impact of SES among Electronics Engineering Students

According to CAES (2020), the primary objectives of engineering courses are to interpret mathematical concepts and apply them to technology for solving both natural and man-made problems. However, Mills and Treagust (2003) and Suh et al. (2021) argue that engineering educators often produce students with a solid foundation in engineering science but insufficient ability to integrate this knowledge into practical workplace applications. This shortcoming is attributed to the lack of appropriate tools for effective interdisciplinary curriculum integration, which hampers a comprehensive understanding of how mathematics can be blended with the social environment. In this context, integrating mathematics into electronic engineering is considered an essential approach to enhance the teaching and learning of electronics-related courses. Zhou (2006) emphasize that, without adequate understanding of integration, students may struggle with the memorization and application of content in electronics courses. Similarly, Froyd and Ohland (2005) assert that integration in engineering education is indispensable, especially in electronics. Sitopu et al. (2024) further highlight that incorporating mathematics into electronics courses stimulates student interest in scientific content. Consequently, mathematical integration in electronic engineering has emerged as one of the most effective tools for improving the teaching and learning of electronics-related subjects.

Mathematics, as a symbolic tool in science and technology education, plays a critical role in helping learners blend and articulate major concepts, such as those related to antennas in engineering education. According to Sitopu et al. (2024), mathematical ideas foster creativity, contextual and in-depth learning, and a systematic approach to problem-solving, thereby enhancing students' command of mathematics. This underscores the indispensable role of mathematics in the teaching and learning of science and technology. By emphasizing mathematics as an instructional tool, learners can develop the ability to generate innovative ideas, which in turn strengthens their understanding of physical sciences, enhances their technological insight, and improves their employability in competitive job markets (Sitopu et al., 2024). Rojko (2004) also highlights the importance of mathematics as a medium for communicating scientific concepts in science and technology education. Its significance is particularly evident when teachers use concrete examples to explain these concepts, demonstrating mathematics as a practical tool that bridges theoretical knowledge with real-world applications. Mathematics equips learners not only for workplace challenges but also for understanding and engaging in real-world situations (Suh et al., 2021). Sitopu et al. (2024) further emphasize that advancements in fields such as mechanics and aerospace engineering were made possible through the application of mathematical content. Similarly, Lindberg (2007) finds that mathematical knowledge enables students to formulate, analyze, and integrate mathematical problems into science and technology education, applying these skills in everyday life. Neglecting mathematics in the learning process of science and technology-related subjects, therefore, risks rendering the entire educational effort ineffective.

Coben (2000) highlights that numerous educational studies on the role of mathematics in students' understanding of science, technology, and engineering (STE) reveal the presence of implicit mathematical content that is often not easily recognized. Similarly, Lindberg (2007) argues that students in engineering and technology education require a specialized form of mathematics that directly supports their ability to relate mathematical concepts to their fields and informs their decision-making processes. This emphasizes the need to cultivate students' capacity to apply mathematical knowledge in various contexts. Redish and Kuo (2015) found that understanding mathematical principles is essential for explaining concepts such as Kirchhoff's law in current electricity, where students often struggle without a solid grasp of the underlying mathematical ideas. This underscores the potential of interdisciplinary integration to help electrical engineering students transfer their knowledge and effectively articulate the abstract concepts they encounter in practice. In the following section, I explore the concept of integration to introduce the model employed in this study and its significance in the teaching and learning of physical electronics as a module.

On the other hand, the role of socioeconomic status (SES) in mathematics integration cannot be overlooked. Hayes highlights that if the SES gap among students is not adequately addressed, it could lead to poor performance among engineering students studying mathematics in universities, particularly in South Africa. Ren et al. (2021) and Valero et al. (2015) further emphasize that factors such as the students' age, learning environment, and the type of school attended play a crucial role in shaping their academic outcomes. Addressing these factors can significantly enhance the performance of engineering students in mathematics-related courses.

2.3 Theoretical Framework

Previous theoretical frameworks have provided valuable guidance for research on mathematics integration. Fasinu and Alant (2023) highlighted the Berlin and White Science and Mathematics Model (BWISM), an interdisciplinary framework deemed a reliable tool for integrating mathematics and science curricula. The BWISM model was designed to facilitate teaching and learning in integrated mathematics and science education. Its steps include: employing mixed methods for data gathering, fostering thinking skills, developing content and conceptual knowledge, and shaping attitudes toward learning and teaching strategies (Fasinu, 2021; Kurt & Pehlivan, 2013). Building on the BWISM model, Davison et al. (1995) proposed an additional five-step framework for integrating mathematics into science. These steps are: discipline-specific integration (e.g., mathematics and science), content-specific integration, the integration process, methodological considerations, and thematic integration (Treacy & O'Donoghue, 2013). Furthermore, Kiray (2010) expanded on Berlin and White's model to enhance its application and understanding in mathematics integration. However, this study reveals that adopting these models to address the impact of learners' socioeconomic backgrounds on understanding physical electronics may not yield positive results. Consequently, the researcher has developed the Socioeconomic Skill-Based Practical Reward Integrative Mathematical Model (SEB-PRMIM) as a more suitable framework for teaching mathematics integration in physical electronics. This model emphasizes the influence of students' socioeconomic backgrounds on their learning outcomes in physical electronics. Details of this model are discussed in the study's discussion section (see Fig. 2).

Based on data collected and existing literature, integrating mathematics and engineering concepts proves to be a highly effective tool in teaching physical electronics. Kiray (2012) also argues that while mathematics and electronics-related courses remain integral to the sciences, achieving a balance across different levels is essential. However, due to the inefficiencies observed in existing models, this study adopts a modified framework to ensure a more effective integration of mathematics into the learning of engineering courses.

METHOD

Research Design

This study employed a mixed methods research approach, combining both qualitative and quantitative data collection and analysis. This approach allows for a comprehensive understanding of the research problem by integrating multiple data sources (Creswell et al., 2008; Poth, 2023). A case study methodology was used to explore participants' strategies for integrating mathematics into their learning of physical electronics. This design facilitated in-depth data collection through surveys, semi-structured interviews, and document analysis, ensuring a thorough investigation of the research objectives (Creswell & Plano, 2011; Lodico et al., 2006). In this research, a case study approach was used to collect data. This approach allowed participants to engage actively through responding to questions and sharing their perspectives. The research primarily operated within a mixed methods paradigm, using questionnaires and documents collected from students to establish their strategies for integrating mathematics into physical electronics learning.

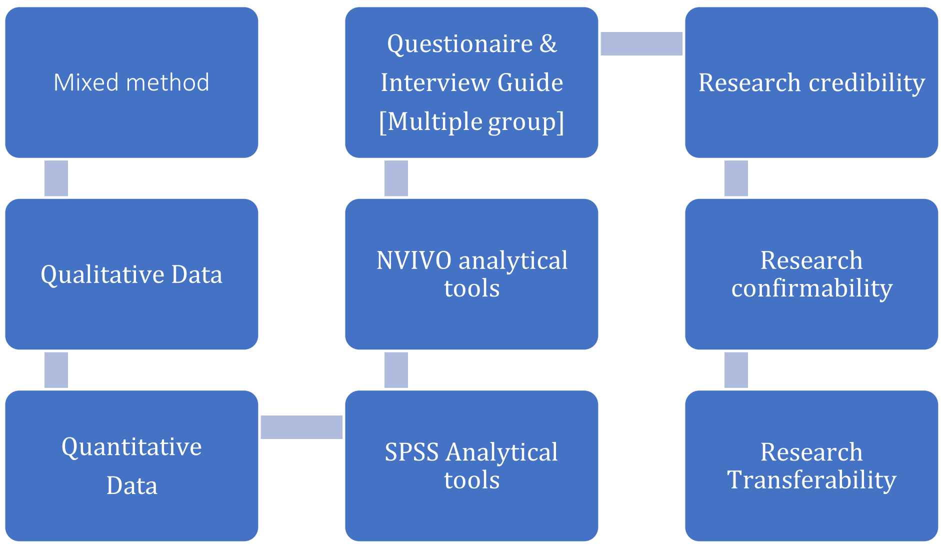

Figure 1. A research flow chart

Participant

The study involved electronics engineering students as the primary participants. A multi-stage sampling technique was adopted to ensure a representative sample. Initially, questionnaires were distributed to all students. From these respondents, a smaller group was selected for observation and focus group interviews to gain deeper insights into their integration strategies. The final phase involved individual interviews and document analysis with selected students to further explore their approaches to combining mathematics and physical electronics in their studies.

Instrument

The study utilized multiple instruments for data collection:

1. Survey Questionnaire: Distributed to all participants to gather quantitative data regarding their integration practices.
2. Semi-Structured Interview Guide: Used in focus groups and individual interviews to collect qualitative data by exploring participants' detailed responses.
3. Observation Protocol: Applied during the observation phase to monitor participants' real-time strategies in integrating the disciplines.
4. Document Analysis: Used to examine students' written responses and other relevant materials to triangulate findings.

Data Analysis

The data were analyzed using computer software tools, including NVivo for qualitative data and SPSS for quantitative data. These tools ensured robust analysis and addressed issues of confirmability, credibility, and transferability. The quantitative data from the surveys were statistically analyzed, while the qualitative data from interviews and document analysis were coded and thematically examined. Findings were synthesized to evaluate how students integrated mathematics into their learning of physical electronics, providing a comprehensive understanding of their strategies.

RESULTS AND DISCUSSION

This section presents the findings of the study based on input from electronics engineering students studying physical electronics, which incorporates mathematical concepts as mandated by the Department of Higher Education and Learning. To effectively report the participants' perspectives, the following subsections were developed for structured discussion:

4.1 The impacts learners' socioeconomic background in integrating mathematics ideas into the learning of physical electronics

To address this research question regarding the identity and background of the learners, data were gathered using the preliminary section of the questionnaire administered to electronics engineering students enrolled in the physical electronics module. The responses were categorized into the following sub-sections: the participants' age, year of registration for their degree and physical electronics module, the school attended at the Grade 12 level, and the subjects studied at the Grade 12 level. These questions aimed to examine the foundational understanding of mathematics held by the electronics engineering students prior to their admission into the Department of Electronics Engineering.

4.1.1. Participants' age

The initial question in the preliminary section of the questionnaire focused on identifying the participants' ages. The responses revealed that the participants ranged from 18 to 21 years old, indicating a reasonable level of maturity before enrolling in the module. As shown in Table 5.1, 40% of the respondents were 19 years old, while 33.3% were 21 years old. Additionally, 13.3% of the participants were 20 years old, and only 6.7% fell within the age group of 18 years.

Table 1. Age of the participants

Age	Frequency	Percent	Cumulative Percent
18	1	6.7	6.7
19	6	40.0	46.7
20	2	13.3	60.0
21	5	33.3	93.3
--	1	6.7	100.0
Total	15	100.0	

The table above indicates that the average age of the students falls between 19 and 21, with a mean of approximately 20 years. This suggests that the age of electronics engineering students may have a significant positive impact on their ability to learn and apply mathematics integration. This aligns with the findings of and Sitopu et al. (2024), who argued that learners' age plays a crucial role in enhancing academic performance, particularly in the modeling of mathematical concepts. Consequently, the importance of students' age in the process of integrating mathematical ideas cannot be overstated. Similarly, Mahdi and Al-Dera (2013) emphasized that a learner's chronological age influences the teaching and learning process, particularly when mathematics integration is involved.

4.1.2. Participants' Academics Degree registered

The second question from the preliminary section of the questionnaire revealed that all participants in this study were electronics engineering students pursuing a Bachelor of Science degree in Electronics Engineering. The Physical Electronics module, a second-year course offered by the Electronics Engineering Department, was taken by all participants. As shown in the table below, 66.7% of the students enrolled in the module for the first time in 2016. Additionally, 20% of the participants first registered for the module in 2015, while 13.3% began in 2014. This indicates that 33.3% of the participants were repeating the module.

Table 2. Year of registration for the degree and the Physical Electronics module

Year of reg. for BSc Degree	Year of Registration of PE module	Frequency	Percent	Cumulative Percent
2013	2014	2	13.3	13.3
2014	2015	3	20.0	33.3
2015	2016	10	66.7	100.0
Total		15	100.0	

Based on the data presented above, students who registered in 2015 demonstrated a strong interest in the integration of mathematical concepts. This is reflected in their responses, which highlight their knowledge and understanding of mathematics integration. Being enrolled in an electronics engineering program provided these students with the opportunity to apply mathematical concepts to their learning of physical electronics. This aligns with findings from previous researchers, who suggest that the degree program chosen by students serves as an indicator of their academic performance during and after their studies (Gómez et al., 2022). For instance, a student with a solid understanding of mathematics is likely to find it easier to integrate mathematical ideas into electronics-related courses.

4.1.3. High School attended by the participants

As indicated in the table below, the participants came from various schooling contexts ranging from public to rural schools. It is significant to note that 73.3% came from public rural schools, whilst 6.7% and 20% came from private and public urban schools, respectively.

Table 3. Type of school attended by the participants for Grade 12

School Attended	Frequency	Percent	Cumulative Percent
Private	1	6.7	6.7
Public Rural	11	73.3	80.0
Public Urban	3	20.0	100.0
Total	15	100.0	

The data above highlights that 73% of the students who participated in the study possess some knowledge of advanced mathematics. When evaluating learners' academic performance at the university level, the type of school attended and certain socioeconomic factors play a crucial role and should not be overlooked (Bayat, 2014). Examining the schools attended by the participants, a significant number of learners who successfully integrated mathematical concepts into their learning of physical electronics came from public schools in both rural and urban areas. This suggests that some public schools in South Africa excel in teaching mathematics-related subjects.

4.1.4. Subjects taken at Grade 12 level

The participants who registered for the Physical Electronics module had completed the required subjects for admission into the Electronics Engineering discipline during their Grade 12 examinations. These compulsory subjects included Physical Sciences, Mathematics, and other science-related subjects. This requirement enables the College of Agriculture, Engineering, and Science (CAES) to assess the competency levels of first-year engineering students in applying mathematics and science to solve engineering problems (College of Agriculture, Engineering & Science, 2016, p. 88). Interestingly, the data indicates that 60% of the participants took seven subjects at Grade 12 level, while 20% reported taking eight subjects, exceeding the standard requirement of six subjects. This suggests that some participants surpassed the typical academic expectations for Grade 12 students.

Table 2. Subjects taken at Grade 12 level

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	7.00	9	60.0	75.0	75.0
	8.00	3	20.0	25.0	100.0
	Total	12	80.0	100.0	
Missing	-----	3	20.0		
Total	15. OO	15	100.0		

The subjects taken by electronics engineering students at the Grade 12 level played a significant role in shaping their understanding of mathematics integration, particularly in the context of the physical electronics course. Sanitema (2022) notes that the performance of students at Grade 12 has a substantial impact on their academic performance at the university level, especially in mathematics-related engineering courses. Therefore, a solid foundation in mathematics at the Grade 12 level is crucial for enhancing students' ability to integrate mathematical concepts effectively. In summary, to address the research question regarding the socioeconomic background of the participants, the following key findings were identified:

- **Age**: The participants' ages ranged from 19 to 21 years.
- **Degree and Year of Registration**: All participants were enrolled in a Bachelor of Science (BSc) in Electronics Engineering, with registration years for the degree ranging from 2013 to 2015. The registration years for the physical electronics module ranged from 2014 to 2016.
- **Type of School Attended**: The participants came from diverse educational backgrounds, including public, private, and rural schools.
- **Subjects Taken at Grade 12**: All participants had taken Physical Sciences and Mathematics at Grade 12, along with one or two additional subjects beyond the standard requirement of six subjects (Vadivel, 2023; Brand, 2020).

These factors collectively had a significant influence on the participants' ability to integrate mathematical concepts into their learning of physical electronics.

4.1.5. Discussion on the learners' socioeconomic background on the learning of mathematical integration

This section provides a summary of the findings related to the research question (RQ) on the participants' backgrounds and their understanding of mathematical integration. The results revealed that the participants' ages ranged from 19 to 21 years. All participants were enrolled in a Bachelor of Science (BSc) program in Electronics Engineering, with registration years for the degree spanning from 2013 to 2015. Their registration years for the Physical Electronics module ranged from 2014 to 2016. The participants came from diverse educational backgrounds, including public, private, and rural schools. They also had a strong foundation in Physical Sciences and Mathematics, as evidenced by their Grade 12 examinations. Additionally, many had taken one or two extra subjects beyond the standard requirement of six subjects.

The findings also showed that 13.3% of the participants had registered for the Physical Electronics module in 2014, 20% in 2015, and 66.7% for the first time in 2016 (Jeevarathinam et al., 2023). This indicates that 33% of the students who registered in 2014 and 2015 were repeating the module, while 66.7% were first-time registrants. The primary reason for repeating the module was their inability to meet the prerequisite requirement, which included completing the mathematics modules Math 1A and Math 1B before enrolling in Physical Electronics. After thoroughly investigating the socioeconomic backgrounds of the participants, the researcher then analyzed the degree of mathematics integration among the students. The findings related to this aspect are presented in alignment with RQ2.

4.2 The confirmation of mathematics integration and its benefits among engineering learners learning physical electronics

To report on the students' perspectives regarding mathematical modeling and its role in learning mathematical integration in physical electronics, a framed question was posed: "Do undergraduate university engineering students integrate their mathematical ideas into their learning of physical electronics? If yes, what are the benefits of mathematics integration to them?" To address this research question (RQ), a semi-structured questionnaire was utilized to gather responses from the electronics engineering participants. This questionnaire comprised five questions, with data for this specific RQ drawn from Questions Three and Four. Participants' responses were evaluated using a Likert scale, coded as follows: "always" (4), "often" (3), "seldom" (2), and "never" (1) (see Table 6).

The responses were categorized into three groups: electronics engineering students who sometimes integrate their mathematical ideas when learning physical electronics, those who often integrate these ideas, and those who never do so (Creswell & Poth, 2018; Poth, 2023). This categorization was designed to assess the extent to which students integrate mathematical concepts into their learning of physical electronics and to highlight the critical role mathematics plays in enhancing the learning process in physical electronics and engineering disciplines. Further exploration of the RQ included additional probing of students' views, specifically asking for explanations about their level of participation in mathematical modeling. A summary of the resulting data is presented below.

Table 5. Participants that integrate some math concepts or not into physical electronics

RQ	Answers from the participants	
Do undergraduate University Engineering students integrate their mathematical ideas into their learning of physical electronics? If yes, what are the benefits of mathematics integration to them?	Yes	No
	93.3%	6.7%

Based on the responses provided by the participants to RQ2, it is noteworthy that 93.3% of the electronics engineering students reported integrating mathematical ideas into their learning. This highlights the critical role of mathematics in understanding and mastering the Physical Electronics module. The inclusion of mathematical concepts is essential for supporting and explaining the physical behavior of electrically related materials. These findings emphasize the importance of mathematics as a foundational subject, as improved mathematical understanding enhances electronics engineering students' technical expertise in both the theoretical and practical aspects of their studies (Fasinu & Alant, 2023). Therefore, fostering mathematical proficiency among students is not only beneficial but also indispensable for their success in engineering-related courses.

4.2.1. Level and benefits of math integration knowledge among the students

Mathematics integration among electronics engineering students was found to vary depending on factors such as age, academic background, and the type of school attended, among others. To further explore this, the researcher investigated how frequently students integrated mathematical concepts into their learning of physical electronics. The table below presents the level of integration as reported by the participants. These levels were categorized to reflect the students' understanding of mathematics integration (MI). The data, analyzed using SPSS and NVIVO software, provides a detailed breakdown of the categories and their corresponding percentages.

Table 3. Participants' responses on mathematics integration in learning physical electronics

Participants' opinions	Frequency	Percent	Cumulative Percent
Never	1	6.7	6.7
Seldom	6	40.0	46.7
Often	6	40.0	86.7
Always	2	13.3	100.0
Total	15	100.0	

It is worth noting that 53.3% of the participating electronics engineering students reported integrating mathematical ideas into their learning of physical electronics, with responses categorized as "always," "often," "seldom," and "never." As shown in Table 6, 13.3% of the participants stated that they always integrated mathematical ideas into their learning, while 40% reported doing so often. Conversely, 40% indicated that they seldom integrated mathematical ideas, and 6.7% stated that they never did. These results are visually represented in the figure below for further clarity.

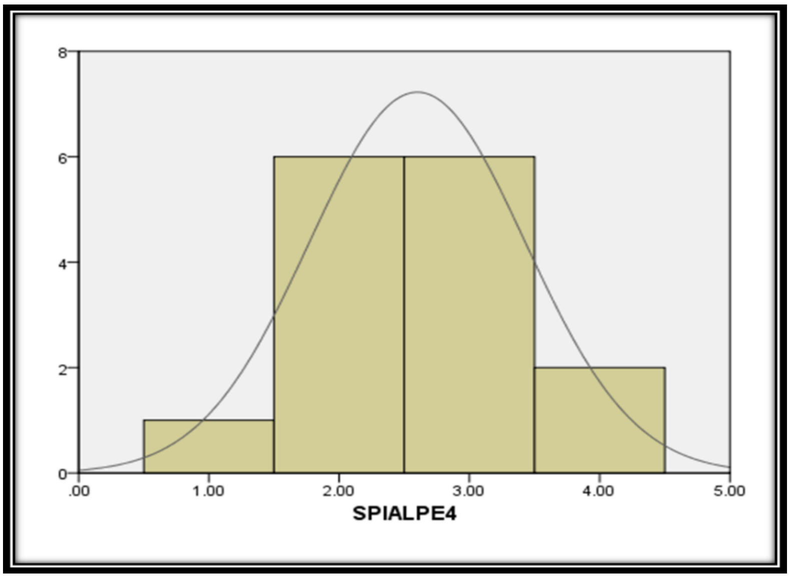

Figure 2. Participants' responses on the use of mathematics in the learning of physical electronics

The data and graph above illustrate three categories of students who integrated their mathematical knowledge into their learning of physical electronics: "Often," "Always," and "Seldom." For analysis purposes, the first two categories ("Often" and "Always") were combined into a single category labeled as the "frequently integrating" group, while the "Seldom" category was referred to as the "occasionally integrating" group. These two broader categories were used to examine the students' justifications for integrating mathematics into their learning of physical electronics. The graph clearly shows that while some students integrate mathematical ideas infrequently, others do so on a more regular basis. This aligns with the findings of Fasinu and Alant (2023), who argue that integrating mathematical concepts is essential for facilitating the learning process in physical electronics within an engineering education context.

4.2.2. Benefits of the frequently integration of mathematics concepts in physical electronics

As shown in Table 6, 53.3% of the participants, equivalent to eight students, identified the integration of mathematical ideas as a common and effective approach to learning the Physical Electronics module. Among these, six students reported integrating mathematical concepts often, while two students stated they always used this approach when studying physical electronics. The following excerpts provide insights into the participants' reasons for integrating mathematical ideas into their learning. These justifications have been grouped into the sub-categories explained below:

I. Help in solving complex engineering problems
As illustrated in the excerpts below, participants S001, S010 and S014 found that the integration of mathematics into their learning of physical electronics helped in solving complex engineering problems: S001: *"I do integrate and it helps a lot in solving a well-integrated engineering problem and tedious equations."* Similarly, participant S010 supported this view by saying that: S010:*"As stated previously, many calculations exist within the module."* Furthermore, another participant S014, was of the same opinion that: S014: "*We integrate mathematical ideas every time it can be explained through maths."*

II. Help in proofs
As shown in the excerpts below, participants S013 and S009 explained that the integration of mathematics into their learning of physical electronics helped in explaining some proofs and theories in engineering. S013: "*There were some integration involved, especially when proving the formula*."

III. Allows for more understanding
S009: *Yes, every idea, theory is proven experimentally and thus mathematical knowledge makes its understanding easy.*" In a nutshell, the results of the three subcategories corroborate that of Wicklein and Schell (1995), who argue that the main aim of mathematics courses or modules it is to help in solving man-made problems alongside knowledge in engineering. The Engineering Council of South Africa supports this in stating that learners' knowledge of mathematics, with the support of their knowledge of science, should help in solving important engineering problems (as cited in CAES, 2020). The participants' ability to integrate mathematics into their learning of physical electronics was to ascertain the level at which they adopted mathematics in solving human-related problems during their application of knowledge in the engineering field. The next section presents the category of students that integrated mathematical ideas into their learning of physical electronics, but not on a regular basis.

4.2.3. The benefits of infrequently integrating of mathematics in physical electronics

The questionnaire responses reveal that 40% of the participants, equating to six students, seldom integrated mathematical ideas into their learning. The justifications for their integration efforts are grouped into the following sub-categories: providing meaning to certain engineering problems, assisting with proofs, and enhancing understanding of the physical behavior of materials. This suggests that while these students occasionally incorporated mathematical concepts into their learning, it was not a consistent practice. Selected excerpts from the reasons they provided are highlighted below:

I. Helps in giving out meaning to some engineering problems
S002: "When we want the meaning of a certain thing, mathematics integration and its equations tend to be helpful". Another student added, "Math integration helps us solve problems and understand concepts better in engineering.

II. Helps in proofs
S006: "You need mathematics for proofs." In a similar statement, another participant commented that: S004: "In test, we have some causal calculation and some proofs." In addition, participant S006 confirmed that: S006: "You need math for proofs."

III. Aids understanding
S003: "Most of the equation is based on physical behaviour rather than maths; very few basic maths needed, physical behaviour demonstration might help."
From line 1 of participant S002 and line 1 of participant S006, their comments show that when they integrated their mathematical ideas into their learning it was for the calculation of some mathematical question and to prove some mathematical derivatives within the module. This finding concurs with Hestenes (2003) discovery that when learning advanced areas in quantum mechanics and electricity, the adoption of mathematics into learning remains unavoidable. The next section presents the issues raised in the study on whether physical electronics can be learned without any knowledge of mathematics integration.

4.2.4. Discussion on the Confirmation of mathematics integration among engineering learners

To understand whether the engineering students integrated their mathematical ideas into their learning of basic electronics, the results revealed that 14 out of 15 students, or 93.3% of the participants, confirmed that they did indeed integrate mathematical concepts into their learning of physical electronics. A detailed breakdown of the findings shows that 40% of the participants, equivalent to six students, seldom integrated mathematical ideas into their learning; the same percentage applies to those who often integrated mathematical ideas into their learning of physical electronics. Additionally, 13.3%, representing two students, stated that they always integrated mathematical ideas, while only one student, equivalent to 6.7%, reported not integrating mathematics into their learning of physical electronics.

The extent to which participants integrated mathematical ideas into their learning was categorized into three levels: Always (constantly/frequently); Often (occasionally); and Seldom (infrequently). The first two categories were combined into a single category referred to as the constantly integrating category, while the seldom category was renamed as the occasionally integrating category. These two categories of description were used to interrogate the students' justifications for integrating, or not integrating, mathematics into their learning of physical electronics.

- **Discussion on the category of the students who frequently integrate their mathematical ideas**

  It was observed that 53.3% of the participants consistently integrated mathematical ideas into their learning of physical electronics. In fact, they explicitly stated that learning physical electronics without mathematics integration was impossible. Three primary reasons were identified for why these students incorporated mathematical concepts into their studies: it helped them solve complex engineering problems; it aided in proving certain physics concepts; and it enhanced their understanding of various physics theories. According to the participants, failing to integrate mathematical ideas into their learning of physical electronics could lead to difficulties in solving problems, deriving formulae, and explaining microscopic phenomena related to electrons. This finding aligns with Hestenes (2003), who asserts that a solid understanding of mathematical concepts such as calculus or geometry enables learners—students, in this context—to express complex engineering problems and develop solutions for them. This suggests that a high capacity for integrating mathematical concepts while learning physical electronics significantly aids students in interpreting technical challenges in electronics engineering, thereby enhancing their academic performance.

- **Discussion on the category of electronics engineering students who infrequently integrated their mathematical ideas**

  According to the results, 40% of the participants seldom integrated their mathematical ideas into their learning. The reasons provided for incorporating mathematical concepts into their study of physical electronics included the role of mathematics in giving meaning to critical engineering problems and its importance in proving key theories in physical electronics. These students emphasized that without integrating mathematics into their learning, they would struggle to understand formulae, grasp certain engineering concepts, measure and calculate key physics phenomena, and solve complex problems.

  This finding aligns with the assertion of Hestenes (2003), who explains that the behavior of engineering devices, such as airplanes, can only be fully understood with the assistance of mathematical tools like calculus. Additionally, mathematics plays a pivotal role in bridging the gap between theoretical principles and practical applications in physical electronics, enabling students to link abstract concepts with real-world engineering challenges. Therefore, the integration of mathematics is not merely a supplementary tool but a foundational necessity in explaining and understanding various aspects of physical electronics. Its role extends beyond problem-solving, fostering critical thinking and enhancing the analytical skills required in electronics engineering.

4.3 Comparative report on the students' background and Benefits of mathematics integration using philosophical views

The findings of the study clearly show that in learning physical electronics, many students integrate their mathematical ideas when faced with specific challenges. The results indicate that over 90% of the participants agreed that they needed to integrate mathematics into their learning of physical electronics in certain situations. These situations often arose from the nature of the problems posed and the teaching approach employed by the instructor during the learning process. This suggests that the complexity of the problems and the instructional methods adopted drive students to rely on the approaches they are familiar with for integrating mathematical concepts into their learning of physical electronics.

It was observed that 53.3% of the participants consistently integrated their mathematical ideas into their learning. These students strongly emphasized that it was impossible to master physical electronics without the integration of mathematics (Valero et al., 2015; Ríordáin et al., 2015). The reasons they provided for integrating mathematical ideas were categorized into three key points: it enabled them to solve complex engineering problems, it facilitated the proof of physics concepts, and it enhanced their understanding of various theories in physics. According to these students, failing to integrate mathematical ideas would lead to significant challenges, such as the inability to solve problems, derive formulae, and explain microscopic phenomena related to electrons. This finding aligns with Hestenes (2003), who asserts that a solid understanding of mathematical concepts, such as calculus or geometry, is essential for students to express and resolve complex engineering problems effectively. This reinforces the idea that mathematics is not only a supportive tool but a foundational requirement for the study of physical electronics. Furthermore, the results underscore the importance of adopting a collaborative learning approach that emphasizes interdisciplinary integration. The findings suggest that this approach is far more effective and reliable than traditional teaching methods, which often fail to meet the demands of modern engineering education. To ensure successful learning outcomes, instructors should prioritize interdisciplinary teaching strategies that blend mathematical concepts with physical electronics to promote a deeper and more comprehensive understanding.

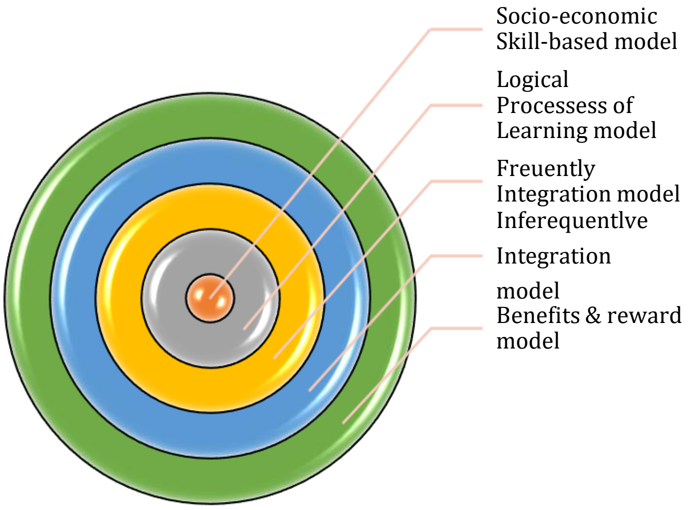

Figure 3. Socioeconomic background-based Practical Reward Mathematics Integrative Model (SEB-PRMIM)

From the data analyzed above, it is evident that achieving practical and meaningful mathematics integration requires students to consider several key aspects, including the Background and Skill Model, the Logical Process of Learning Model, the Frequently Integrative Model, and the Infrequently Integrative Model (Fasinu & Alant, 2023; Jeevarathinam et al., 2023). The perspectives of students learning physical electronics suggest that their level of understanding during mathematics integration is heavily influenced by their background. Factors such as the type of school attended, academic performance at Grade 12, and the degree program they are enrolled in play a significant role in motivating their interest and improving their performance in mathematics-related courses, with only a few exceptions. This implies that socioeconomic factors also contribute to students' ability to integrate mathematics effectively.

Additionally, the data indicates that during the mathematics integration process, some learners adopt logical approaches that enhance their ability to understand and apply mathematical ideas. These logical processes have proven to be instrumental in supporting their comprehension and facilitating integration (Jeevarathinam et al., 2023; Vadivel et al., 2023; Valero et al., 2015). Furthermore, it was observed that while some students integrate mathematical concepts frequently, others do so on an infrequent basis. Despite these variations, participants unanimously acknowledged that all stages of integration have contributed to generating benefits that ultimately enhance their learning process. In conclusion, a well-executed integration of mathematical ideas into the learning of physical electronics can lead to a comprehensive understanding of engineering-related courses. This can be effectively achieved through the application of the SEB-PRIMM model, which emphasizes socioeconomic and skill-based approaches to mathematics integration.

Implications

This study underscores the critical role of socio-economic factors in shaping students' ability to integrate mathematical concepts into physical electronics education. The findings highlight that addressing socio-economic disparities, such as school background and access to quality education, can significantly improve students' academic performance and their ability to apply mathematical knowledge effectively in engineering contexts. The introduction of the SEB-PRMIM model provides a structured approach to mitigating the challenges posed by socio-economic differences, offering practical strategies for educators and policymakers to enhance curriculum design and delivery. By fostering interdisciplinary collaboration between mathematics and engineering departments, this research advocates for a more cohesive teaching approach that aligns with real-world applications, ultimately preparing students for professional challenges in engineering fields.

Limitations and Suggestions for Future Research

Despite its valuable contributions, this study is limited by its focus on a single module within a specific university context, which may restrict the generalizability of the findings. Additionally, the reliance on self-reported data introduces the possibility of response bias. Future research could expand on this study by exploring mathematics integration in other engineering disciplines or universities with diverse socio-economic settings. Longitudinal studies could provide deeper insights into the long-term impact of socio-economic factors on mathematics integration. Moreover, incorporating advanced technologies, such as AI-driven learning analytics, could enhance the understanding of individual learning trajectories and offer personalized interventions. Future investigations might also consider the role of teacher training and its influence on the effective integration of interdisciplinary concepts in engineering education.

CONCLUSION

Findings confirm that improving engineering education depends on identifying and bridging the gaps between disciplines integrated into the curriculum, particularly between mathematics and physical electronics. While physical electronics heavily relies on mathematical concepts, the way these concepts are handled remains a concern. Compounding the issue is the tendency of lecturers to work in isolation, creating barriers to collaboration and knowledge-sharing across departments. For instance, an analysis of course designs from a university reveals significant overlap between the mathematics and physical electronics curricula, yet little interdisciplinary cooperation exists. Many engineering lecturers prioritize their specific disciplines, neglecting collaboration with fields such as mathematics and education, which exacerbates gaps in engineering education. This disciplinary divide, if left unaddressed, could further disadvantage students. The study also shows that electronics engineering students frequently integrate mathematical concepts, such as calculus and differentiation, into their learning of physical electronics, with their level of integration influenced by socioeconomic factors like school attended, age, family status, and environment. Proper implementation of interdisciplinary integration could yield significant benefits, including better course comprehension, easier mastery of engineering-related subjects, and the ability to derive and prove engineering formulas. Thus, mathematics integration is an essential tool for overcoming challenges in mathematics-intensive engineering courses and fostering a more effective learning experience.

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