MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(1), em2214
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/12797

University electronics engineering students' approaches of integrating mathematical ideas into the learning of physical electronics in basic electronics

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Received 03 July 2022 ▪ Accepted 14 October 2022

Abstract

The limited knowledge of mathematical ideas and the high dropout rate of students in the schools of engineering throughout the country each year is alarming. One of the reasons attributed to this high failure rate is the students' inability to integrate and apply the main mathematics constructs covered in the engineering courses. In this regard, this paper takes as its point of departure that the integration of mathematical concepts in engineering courses is unavoidable, particularly, in physical electronics. It gives credence to the objectives of engineering courses, that students should be able to interpret mathematics during design, apply appropriate technology to solve natural and man-made problems, evaluate engineering solutions, and appreciate a broad spectrum of knowledge. It thus argues for the use of a practical pedagogical multidisciplinary integrative model in the learning and teaching of engineering courses. The focus of the paper is on electronic engineering students' knowledge of the mathematical ideas adopted and how the students blend and integrate advanced mathematics into their learning of physical electronics in a basic electronics course. The participants report that certain strategies are adopted when integrating mathematical concepts into the teaching and learning of physical electronics. These include Identification of the problem, selection of appropriate mathematical ideas, the analysis of the problem mathematics concepts, recognizing the degree of the mathematics concepts usage during integration, memorization method and the final result of interdisciplinary integration. This study was carried out using a qualitative approach of data collection in order to report a naturalistic view of the 15 electronics engineering students learning physical electronics as a course.

Keywords: electronics, mathematics, integration, engineering

INTRODUCTION

Mathematics integration has been found to be a reliable tool that facilitates and produces a mathematically competent engineer due to the adoption and the learning of multiple disciplines in a multidisciplinary manner (Ng et al., 2022). But it could be said that the limited understanding of the present learning style among engineering students has led to a high dropout rate among electronics engineering students not only in South Africa but globally (Jones, 2009; Redish & Kuo, 2015). One of the contributing reasons for this is students' inability to integrate and apply the main mathematical constructs involved in scientific content (Tuminaro, 2004). In support of this, Jones (2009) and Zhou (2007) allude to the fact that without an adequate understanding of *interdisciplinary integration*[1], the learning of the content involved in electronics-related courses might become difficult for students.

Similarly, Froyd and Ohland (2005) confirm that interdisciplinary integration in engineering education is

[1] Interdisciplinary integration can be defined as the process in which students and instructors come together to analyze differences in disciplinary approaches to a problem and to work towards a synthesis, resulting in a new, more comprehensive view than allowed by the vision of any one field (Boix-Mansilla, 2008).

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Contribution to the literature

- The different ways in which undergraduate electronics engineering students integrate mathematical ideas in learning physical electronics.
- The conditions that warrant or inform the adoption of the selected forms of integration in physical electronics.
- The proposed model, the practical pedagogical multidisciplinary integration model, is useful for improving the integration of the mathematical ideas into the learning of Physical Electronics and other engineering courses.

unavoidable, particularly in electronics engineering, because some of these modules taken in this field comprise different disciplines.

In addition to this, Chen and Chen (2021) report that adopting an interdisciplinary integrative approach of learning mathematics-related ideas in engineering context may go a long way in facilitating the teaching and learning methods in engineering department. On this note, Hestene (2003) argues that the integration of mathematics into solid-state physics and electromagnetism has the potential to assist engineering students improve their abilities to analyze electrical-related problems. Mills and Treagust (2003) further explain that the integration of mathematics into the learning of electronics-related courses may help in stimulating students' interest in scientific content.

Studies have confirmed that the integration of mathematics in electronic engineering is one of the most effective tools in learning electronics-related courses (Berlin & White, 2010; Jones, 2009; Tuminaro, 2004; Zhou, 2007). Despite the importance of mathematics to the learning of science-related courses, it is unfortunate that many engineering students have a personal bias against mathematics that affects their ability to achieve better results in their major and minor courses. This, according to Redish and Kuo (2015) and Tuminaro (2004), has led to a high failure rate among university electronic engineering students. Other factors that contribute to their inability to recognize, apply and integrate mathematical ideas into their learning in electronics engineering courses, in particular physical electronics, are poor methodology inherited from their lecture rooms, and lack of interdisciplinary integrative knowledge among many other (Berlin & White, 2010; Willcox & Bounacox, 2004).

A similar experience was discovered by a researcher who reported that, before the introduction of merged disciplinary areas[2], students were able to concentrate on their own area of specialization, as revealed in Aristotle's classification of disciplinary areas (Repko, 2008). However, modern science was introduced, which involves the merging or integration of physics, chemistry, mathematics and state of material, which comprises a major combination of physical electronics, semi-conductor physics and quantum physics (Tuminaro, 2004). With this came the problem of how to integrate these disciplines in order to facilitate the learning process (Youngblood, 2007). The disciplines combined together to form physical electronics still focused on the main science of semi-conductor physics and physical electronics without considering the integration of key mathematical ideas (Hestene, 2003; Redish & Kuo, 2015). Due to this neglect, many students attending these courses have had to repeat the year because they lacked the necessary strategies to integrate the mathematics involved into the learning of physical electronics (CAES, 2020).

In as much as the objectives of electronics engineering education are to identify the needs of society and to apply the innovations of science and technology to solving human problems (CAES, 2020; Cassey, 2009), the necessity for mathematical integration in interconnecting, restructuring and designing of certain electronic equipment in a real life situation cannot be overemphasized (Khozali & Karpudewan, 2020). But it is unfortunate to report that some electronics engineering students lack enough capacity to integrate the appropriate mathematical ideas into their learning of physical electronics (Redish & Kuo, 2015). It is on this ground that this study discusses the meaning and strategies of interdisciplinary integration of mathematical concepts in engineering-related courses.

The objectives of this paper are to investigate the mathematical ideas that engineering students integrate when learning physical electronics, describe how these students implement their ideas in terms of integration and report the possible approaches and strategies adopted when integrating mathematics into the learning of physical electronics. Therefore, this paper reports empirical findings on the approaches adopted by electronic engineering students when integrating their mathematical concepts into their learning of physical electronics. It concludes with a brief discussion and summary on how engineering students integrate their mathematical ideas when learning physical electronics. In order to report the university electronics engineering

[2] Merged disciplinary areas can be defined as the bleeding of two or more disciplines. This is where the differences in disciplinary areas are brought together to solve a problem, and to work towards synthesizing a new and comprehensive outcome.

students' approaches and processes of integrating mathematics ideas into their learning of physical electronics, the research question stated below serves as a guide for the study:

What and how do electronics engineering students integrate mathematical ideas into their learning of physical electronics?

For a better understanding of the paper, the next section reports the views of other researchers on interdisciplinary teaching and learning strategies.

Meaning & Strategies of Interdisciplinary Integration of Mathematics Concepts into Engineering Courses

The term 'interdisciplinary integration' is a logical approach of blending, fusing, and interconnecting many ideas and views together in order to generate a new one (Khozali & Karpudewan, 2020; Youngblood, 2007). Similarly, it could be regarded as a dependable tool adopted in balancing the discrepancies between mathematics, science and technology in a curriculum that integrates these disciplines. On this note, an interdisciplinary integrative approach can therefore be referred to as the incorporation of two or more ideas and courses in which the connections are made between the courses, but the two courses remain united without any separation (Repko & Szostak, 2016). Repko (2008) describes *interdisciplinary integration* as method of creative blending of ideas and knowledge coming from different disciplinary contexts in order to generate a more comprehensive advancement. In view of this, LasFever (2008) argues that the word 'interdisciplinarity' generated from interdisciplinary integration allows the generation of two or more disciplines, which brings in a new development of ideas, and a new area of specialization. As a result of this, some researchers asserted that having better understanding of the impact of disciplines in interdisciplinary studies should be a focus point for a full understanding of the term 'interdisciplinarity' (Repko & Szostak, 2016). On this note, interdisciplinary integration could be regarded as a new term, which Newell (2006) confirmed to be challenging, because the word 'interdisciplinary' places much emphasis on the disciplinary area thereby neglecting other perspectives. On this ground, he further stressed that speaking about inter-perspective studies may be of benefit to all areas involved (Jones, 2009; Newell, 2006). In view of this, researchers further explain that the goal of interdisciplinary approaches is not only to resolve or fuse all topics, but to engage some specific aspects that meet some vital condition required in an integrative curriculum (Repko & Szostak, 2016; Ríordáin et al., 2016). Thus, Youngblood (2007) cautions that not every course or topic in science should necessarily be an interdisciplinary course and not every program should be comprehensively interdisciplinary. Therefore, there is a need to allow for flexibility while planning and integrating an interdisciplinary curriculum. This would allow the number of interdisciplinary courses or subjects that could be taken up by students to differ from one student to another (LasFever, 2008). In support of this, students should possess multiple ideas on interdisciplinary courses and interdisciplinary approaches, which could assist them to develop a habit of moving from disciplinary separation or discrimination to moving beyond logical skills and become a critical thinker (Jones, 2009; Youngblood, 2007). This implies that the integration of mathematics with physical electronics can only be possible provided the approaches of implementing an interdisciplinary integrated curriculum is carefully done and maintained during integration.

It is on this ground that the following four-pronged strategy could be used within engineering courses when integrating mathematics into engineering-related courses, as suggested in the literature (Repko & Szostak, 2016). Firstly, there is a need to *identify the problems* at ground level, initiating the process of blending problems together bearing in mind the prevailing conditions. This is followed by *development of motivational skills* to solve problems, being conscious that time is open ended, having good observation skills, and relying on group work (Mills & Treagust, 2003; Youngblood, 2007). Developing confidence in analyzing and explaining concepts will also assist in learning within an integrated curriculum (Zhou, 2007). Furthermore, *having a proper understanding of a question* before answering it becomes important during integration (Lodico et al., 2010). In addition to this, the *provision of a quantitative description of the problem*, planning a solution to the problem, carrying out a plan, considering the coherency and consistency of the formula, and evaluating the obtained solution becomes important (Repko & Szostak, 2016).

Another set of steps that is believed could assist learners in learning electronics-related courses is as follows: delivering a creative act, adopting a systemic approach, considering the subject's context, selecting a good conceptual tool to be used, and working with the expectation of obtaining a good result (Hestenes, 2003; Repko, 2008). Similarly, Jones (2009) also suggests some valuable steps and strategies that an integrated curriculum expert could adopt when implementing an interdisciplinary curriculum: learner's readiness, selection of a team, considering the structure of the selected team, developing the selected team, planning a schedule for the team and finally supporting the team with professional development.

Most of the strategies explored above do not seem to be adopted by undergraduate electronic engineering students in their learning. Therefore, there is a need to consider their abilities to combine subjects, specifically when learning about semi-conductors so that this area of study could be improved upon. Interdisciplinary integration involves students fusing different aspects of interdisciplinary insights, to persuasively advocate, maintain, challenge and dismantle disciplinary insights (Cantwell et al., 2014), which will invariably assist their understanding. Therefore, as teachers remain the only agent of facilitating the process of teaching and learning their impact and role in interdisciplinary integration cannot be over-emphasized.

THEORECTICAL FRAMEWORK

Several theories and models proposed for teaching and learning of the integration of mathematics with science have been advanced, among which are Campbell and Henning (2010) and Fogarty's (1991) interdisciplinary model, and Kiray's (2012) balanced model. On a brief note, Fogarty's (1991) model works on the integration of mathematics in a multidisciplinary way. Therefore, the interdisciplinary curriculum model could be described as a framework which assists the teacher in the interrogation of common problems, topics, sub-topics, issues, and themes by adopting two or more disciplines with some sound integration strategies (Cantwell et al., 2014). In view of this, the combination of the two frameworks were used in the production of both models as reported later in this study.

The adoption of both Fogarty (1991) interdisciplinary model and Kiray's (2012) balanced model was further modified in the study using the available data. Fogarty's (1991) interdisciplinary model helps in dealing with the process of integrating topics and concepts across the disciplines. This eventually gave room for the researchers to share ideas. The ***sequenced model*** sees curriculum as an entity, which is connected by rearrangement in serial order. The ***webbed model*** reports a curriculum as a singular discipline, which allows departmental blending of ideas, while the ***threaded model*** is seen as a big idea, which allows linking of skills. The ***shared model*** sees curriculum as a tool to bring two or more disciplines together through overlapping, and the ***integrated model*** sees curriculum as a tool that is used in viewing the interdisciplinary topics and concept being overlapped (Campbell & Henning, 2010; Fogarty, 1991). In Fogarty's (1991) model, as explained above, there is a wide gap between learners' affective domain and the measurement of assessment, which was absent in his model. In order to explore their abilities to integrate mathematics together with physical electronics, we introduced Kiray's (2012) model, which is the only integrative model that took care of the conceptual element, which works on the students' skill, while the contextual aspect of the model resolves the students' knowledge on the subject. The methodological aspects resolve the teaching and learning style of the students and lastly, the assessment of learning was also important during interdisciplinary integration (Kiray, 2012). Therefore, in as much as the integration of mathematics and physical electronics involved the combination of the above stated frameworks suggested by both Fogarty (1991) and Kiray (2012), in view of this, the process of integrating mathematics with physical electronics was found to be possible.

METHODS

The research participants targeted for the study were electronic engineering students taking physical electronics in a university in South Africa. This study adopts a qualitative research approach having considered the importance of the data needed to describe the strategies adopted by electronics engineering students of physical electronics. At the first stage of the data collection, survey questionnaires were distributed to electronic engineering students taking physical electronics as a module (Creswell & Poth, 2018). During the process of data collection, it was discovered that only a few electronics engineering students taking physical electronics returned their survey questionnaires. The next stage of the data collection commenced after the researchers carefully selected some of the students having preliminary knowledge of the integration of mathematics with physical electronics. We were aware that some students were unwilling to participate in the study as a result of some of them having a biased notion that the researchers were agents sent by the university to measure their lecturer's competency in teaching physical electronics. As a result of this, many students withdrew from the study, leaving only 15 respondents. During the data collection stage, a semi-structured survey questionnaire was used for the process of data collection. This helped us to confirm whether electronics engineering students integrated their mathematical ideas into their learning of physical electronics. Similarly, in order to identify the strategies adopted by electronics engineering students when integrating mathematics with physical electronics, a semi-structured interview guide was used in probing their views. These approaches aligned with Bloomberg and Volpe's (2018) suggestion on qualitative approach of data collection.

At the end of the data collection process, we were able to record sufficient empirical results to validate the electronics engineering students' approaches to integrating mathematical ideas with their learning of physical electronics.

DATA, ANALYSIS, RESULTS, & DISCUSSION

This section presents the responses gathered from electronics engineering students taking physical electronics. Using a survey questionnaire, and the interview guide, we conducted an expository analysis to answer the stated research question. The results were organized around these topics: aspects and timing of integrating mathematical ideas into the learning of physical electronics, approaches of integrating mathematical ideas into the learning of physical electronics, and summary of the approaches and the appropriate teaching model applicable for integrating mathematical ideas into the learning of physical electronics

Aspects and Timing of Integrating Mathematical Ideas into the Learning of Physical Electronics

The findings revealed the following as the aspects of the mathematical ideas that were integrated when learning physical electronics, and these includes calculus, integration, differential calculus, and algebra, among many others. The excerpts below justify why this occurred, and again, their justification is grouped into three categories:

1. *Constantly adopted calculus and integration into their learning,*
2. *Infrequently adopted calculus and algebra,* and
3. *Appropriate timing of integrating the mathematical ideas when integrating mathematics into their learning.*

Constant adoption of calculus and integration of mathematical concepts

To confirm the extent of usage or the consistency in the adoption of this aspect of mathematics, the following responses were captured; participant S001 was of the opinion that

> "Obviously we integrate calculus, integration and differentiation" (S001, interview).

Similarly, participant S015 confirmed that

> "I think integration and derivatives are used" (S015, interview).

It can be seen that participant S001 used calculus constantly to express his views and interpret some difficult concepts. This implies that calculus helps students in explaining the electrical behavior of electrons. Similarly, participant S015 was of the opinion that the constant integration of derivatives is necessary, which shows that an integration approach in solving equations cannot be over-emphasized.

Infrequent adoption of calculus and algebra when integrating mathematics concepts

In reporting the extent of the mathematical aspects adopted, their comments are as follows: Participant S002 maintained that

> "You need to be good in calculus, at a point you need to apply differentiation and at another point you may need to apply algebra as well" (S002, interview).

While participant S003 pointed out that

> "… I think differential calculus and calculus are used because we derive some formulae" (S003, interview).

Based on the comments of participants S002 and S003, they they infrequently used calculus and differentiation to interpret concepts that may be difficult, as stated above. However, S002 stressed the fact that a strong knowledge of calculus is required because of its importance when applying it to electrical/electronic-related problems. This finding corresponds with Balanis (2016) and Hestenes (2003), who report that a proper understanding of calculus and differentiation would help to explain concepts at a microscopic level. In addition to this, the view of participant S002 implied that algebra also helps to explain the behavior of electrons. These findings are in line with those who maintain that electronic engineers are of the opinion that physics ideas can only be explained using algebra (Balanis, 2016). Therefore calculus, differentiation, algebra, and integration remain the common aspects of mathematics adopted during the learning of physical electronics.

Appropriate timing of integrating the mathematical ideas when integrating mathematics into their learning

To integrate mathematics at infrequent basis, the researchers further probed into the actual time that electronics engineering students introduced mathematical ideas to support their answer when learning physical electronics. This was done using the interview guide designed for the study. The result confirmed the actual timing of introducing the appropriate mathematical ideas when learning physical electronics. The participants' responses in this regard are given below.

S002 reports that

> "... obviously, the problem there is that they [problems] come up with numbers saying this one consist of this and this, and this, all the parameters have some mathematical relationships that is when you need to apply your mathematical tool to bring your result" (S002, interview).

Alternatively, participant S003 confirmed that:

> "Yeah ... eh, you cannot separate physics from mathematics" (S003, interview).

On this note, the researchers further questioned if, "It means that you apply both of them together." While S003 replied that

> "Yeah that was why I initially said mathematics it is the language of physical electronics" (S003, interview).

Furthermore, in order to ascertain views of the participants on the timing of integration, some students reported the exact time mathematical ideas were introduced. The responses supplied by the participants are presented below.

Participant S001 suggested that

> "It is very crucial because engineering link everything it is like a tool in learning of physical electronics" (S001, interview).

From line 2 and 3 of the comment made by participant S002, it was clear that the actual time when a learner brought an aspect of mathematics integration into his learning of physical electronics could be traced to the availability of multiples of mathematical variables present in a given concept. In terms of this, even an infrequent response meant that mathematics remained a useful tool in bringing meaning to an engineering problem. Similarly, participant S003 was of the opinion that mathematics is the main language that the module uses in its presentation. In fact, he believed that physical electronics and mathematics are like Siamese twins that can never be separated. Therefore, mathematics remains integral to the proper functioning of the module during the learning process. The participants clarified that when constantly adopting calculus and the integration of mathematics into their learning, the timing of these electronics engineering students when blending some aspect of mathematics into their learning of physical electronics was important.

Furthermore, from participant S001's comment, it can be clearly seen that the timing of introducing mathematical ideas into his learning of physical electronics did not apply because mathematics is a tool that links major aspects of the engineering-related modules and topics together. In this regard, he specifically likened mathematics to a constant tool that he applied when learning physical electronics; he found them to be inseparable from the physical electronics content in the module.

Approaches of Integrating Mathematical Ideas into the Learning of Physical Electronics

In order to ascertain the process and how the participants integrated their mathematical ideas into their learning of physical electronics, the participants were asked to explain the methods and processes that they adopted during the integration process ***when constantly integrating calculus and mathematics into their learning.*** Their responses were, as follows.

Participant S001 commented that

> "… basically, you need to look at what your question is asking and also analyze the data that had been given to you then you formulate and integrate expressing your answer, which may assist you in getting your final answer. More so, it is very good because mathematics ... actually you need to learn from your mistakes and approach the question by analyzing the data in order to have a sound understanding of the main outcome" (S001, interview).

Participant S015 suggested that

> "I will apply my knowledge in either partial derivatives or use this concept in solving out the problem" (S015, interview).

From line 1 and 2 of the comments of participant S001, it is suggested that during the process of mathematics integration, the first process is to consider the given question, after that you devise the formula to be used in solving the problem, and then the integration of the expression is carried out before concluding and applying the solution to the problem. He also stressed that the analysis of the problem is important. This finding corroborates that of with Repko and Szostak (2016), who found that during the process of interdisciplinary integration, the approach of identifying the problem, carrying out the analysis, and solving the problem was unavoidable. Similarly, participant S015 expounded that the understanding and application of his personal knowledge to the problem remained one of the main methods that helped him in learning physical electronics. Students constantly adopted these measures during their learning of physical electronics to improve their proficiency.

Similarly**, when integrating mathematics ideas on an infrequent basis**, participant S002 elaborated on his answer with illustrations of the steps that assisted him in the interdisciplinary integration of mathematics into physical electronics:

> "… It depends on the problem you are facing, for instance, you need to first elaborate on the problem you are given from the material you are given and then from there you will be given that the number of electron are this much and proton number are this much, how many electrons will be there and from that is where you need to convert from physics to looking for mathematical tools to work out certain given parameters having been given all the needed formula" (S002, interview).

While participant S003 confirmed that

> "Yeah, I think from the theory, we try to understand and then work out on the mathematics approximation from the theory" (S003, interview).

From line 1, 2, and 3, participant S002 confirmed that whenever he felt like integrating his mathematical ideas into his line of physical electronics, he took the time to identify the problem first, after which he adopted the

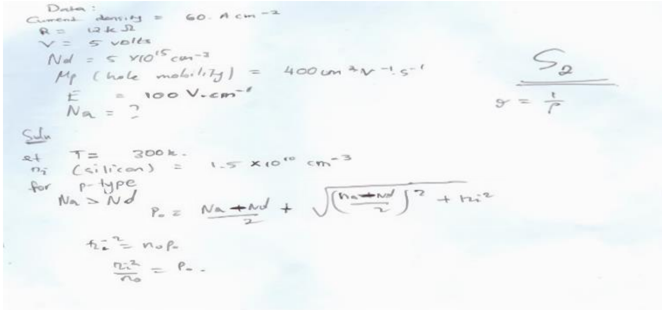

Figure 1. S001' response (Source: Interview, S001)

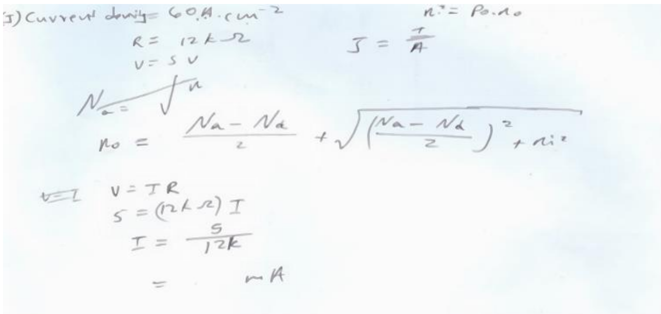

Figure 3. S002's response (Source: Interview, S002)

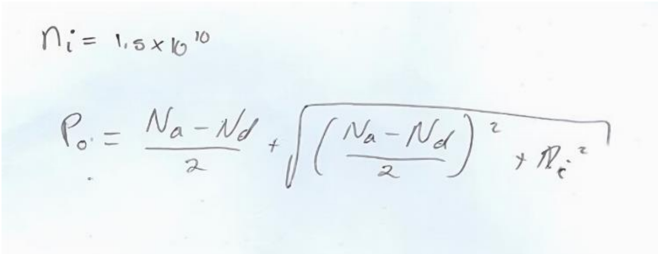

Figure 2. S015's response (Source: Interview, S015)

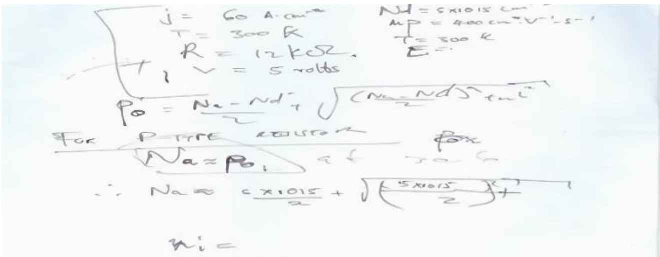

Figure 4. S003's response (Source: Interview, S003)

variable given by manipulating them using the appropriate formula in order to obtain his final answer to the problem. This is in line with the findings of Repko and Szostak (2016), who report that there is a need to first identify the problem before critically structuring an appropriate way to face and solve the main problem. Furthermore, participant S015 confirmed in his comment that the identification of the theory behind a concept is an approach that helped him to solve the mathematical aspects that needed to be integrated. Therefore, going by their categories, participants S002 and S003 infrequently adopted these methods and approaches when learning physical electronics.

On a practical note, the worksheet of the participants shows that mathematical ideas are being integrated when working on physical electronics. These are displayed in S001's response as shown in **Figure 1**.

Similarly, participant S015's response of 'constant integration' to a sample question is displayed in **Figure 2**.

In addition to this, S002 and S003 argued on their integration capacity during the learning of physical electronics on an infrequent basis using a sample question. The responses of the participants that they 'infrequently integrate' mathematical ideas into their learning of physical electronics are displayed. S002's response is shown in **Figure 3**.

Furthermore, participant S003's worksheet continues in this manner, as displayed in **Figure 4**.

Evidence from the worksheet of participant S001 shows that although the participant claimed that he constantly integrated his mathematical ideas into his learning of physical electronics, this was not integrated. But during proper interdisciplinary integration, the following steps were adopted: first of all, he had to identify the problem, after which he needed to select the appropriate equation to solve the problem. Then he should have analyzed the problem by solving the algebraic part of the formula before moving on to the final aspect of combining the problem with the intention of arriving at a reasonable design statement. It is unfortunate that during a practical session, participant S001 was only able to locate the problem and suggest the appropriate formula, but was not able to analyze the problem, which affected the design stage and the final outcome. In a similar vein, the second participant (S015) from the 'constantly integrated' group did not even use any practical knowledge. He identified the problem and selected the formula, after which he could not go further in introducing the variable and blending the physics involved with the mathematical ideas required. On this note, the aspect of constant integration of mathematical ideas into the learning of physical electronics confessed by some of these electronics engineering students was not practically seen because they lacked knowledge on interdisciplinary integration.

Participant S002 claims that he infrequently integrated his mathematical ideas into his learning of physical electronics; instead, he adopted the following steps. First of all, there is the identification of the problem, the selection of the appropriate equation to solve the problem, the analysis of the problem using an algebraic derivation format before moving on to the final stage of integrating the problem with the intention of coming up with a reasonable design statement. It was unfortunate that during the practical session, the participant was only able to locate the problem and suggest the appropriate formula, but was not able to analyze the problem, which affected the design stage and the outcome.

Similarly, the participant (S003) of the 'infrequently integrate' group tried as much as possible to integrate the mathematical variable into the selected formula but missed a particular aspect of the formula. This process of jumping ahead of the logical steps prevented him from properly integrating his mathematical ideas and solving the problem. So, the aspect of 'infrequently integrating' mathematical ideas into the learning of physical electronics, as reported by these electronics engineering students, was not seen because they lacked knowledge on integrating mathematics into their learning of physical electronics. All these challenges observed by the researchers tie in with the view of Bissell and Dillon (2000) who reported that some of electronics engineering students turned to a problem analysis by shifting their concentrations to mathematics calculations.

Summary of the Approaches & Appropriate Teaching Models Applicable for Integrating Mathematical Ideas into the Learning of Physical Electronics

The findings gathered regarding the electronics engineering students' constant integration of mathematical ideas show that 75% of the participants constantly adopted the following methods when integrating mathematics into physical electronics: identification of the problem, analysis of the problem, using the appropriate tool or formula to solve the problem, and calculating and measuring the materials involved. The skills and the methods suggested by these participants are considered to be useful tools by many inter-disciplinarians in the blending process of two or more disciplines. Repko (2008) confirms that the identification of the problem, analysis of the problem, the recognition of common ground, the creation of a formula or approach to be adopted in solving the problem, among many others, are some of the ways to merge some aspects of two or more disciplines. In light of this, for a better understanding of physical electronics, the use of this approach when learning physical electronics would be of immense help to students.

Furthermore, the findings show that 50% of the participants infrequently adopted this method when integrating calculus into the learning of physical electronics, while 25% of the participants did adopt this method when integrating algebra into their learning of physical electronics. This shows that some of the students adopted the following approaches: the identification of the problem, recognizing the variables available for solving, conversion from one unit to another, the allocation of an appropriate formula for a problem, integrating the variables, and finally solving the identified problems on an infrequent basis during their learning of physical electronics. This corroborates the work of Repko (2008), who reports that the identification, analysis and adoption of these appropriate ways for solving interdisciplinary problems assists students by allowing them to resolve multidisciplinary problems. Therefore, even infrequent integration when learning physical electronics will be helpful because this course remains a multidisciplinary one.

In addition to this, gathering from the results, as indicated in their worksheets, there is clear evidence that most of the students lacked a strong ability to integrate their mathematical ideas into their learning of physical electronics. However, although most of the participants constantly selected the appropriate formula that could be used in answering the given problem, only 25% of the participants were able to identify the given problem. It is unfortunate that none of the participants were able to synthesize the problem, integrate the problem or arrive at a solution, which invariably resulted in none of the participants being able to produce a simple design statement in line with the problem. This implies that they lacked knowledge regarding the interdisciplinary integrative approach of introducing mathematical ideas into their learning of physical electronics when it comes to a practical question. The constant identification of the problem was common to all of the participants, which was coupled with the selection of the appropriate equation, but the challenge still lay in their inability to integrate the variables, blend the physics involved and resolve the problem using an interdisciplinary approach.

Therefore, the introduction of interdisciplinary integrative knowledge could impact the students' ability to blend their ideas better. The results show that some of the electronics engineering students who confirmed that they infrequently integrated their mathematical ideas into their learning of physical electronics in fact did so infrequently, although 100% of the participants were able to identify the given problem. Alternatively, 50% of the participants who infrequently integrated their mathematical ideas were able to select the appropriate formula from the formula table given. In addition to this, only 50% of the participants were able to synthesize and integrate some minor part of the problem into their learning. On the negative side, none of the participants were able to reach any solution. This also applied to the design stage of the problem. This implies that although they said they integrated mathematics into their learning, the main a key competency of their profession was missing. This means that some of them lacked knowledge of an interdisciplinary integrative approach to be used in their learning of physical electronics. **Table 1** carefully highlights the approaches of integrating mathematical ideas with some common examples as found among the participants.

From **Table 1**, it is clearly seen that during the teaching and learning of physical electronics, some students were found to integrate some mathematical ideas into their learning in the department of physical electronics. Given the views of the participants, the interdisciplinary integration of mathematical related courses could not be regarded as an option, but a

Table 1. Approaches and examples of integrating mathematical ideas when learning physical electronics

S/N	Approaches of integrating mathematics concepts in physical electronics	Examples of strategies	Appropriate timing of interdisciplinary integration
1	Identification of problem	Reading & understanding of given electromagnetic related problem	During learning process, assignment, & examination period
2	Selection of appropriate mathematics ideas Analysis of problem mathematics concepts	Choosing appropriate mathematical ideas relevant to a given question, e.g., calculus, integration, differential calculus, & algebra	When integrating mathematical ideas into learning of physical electronics
3	Recognizing degree of mathematics concepts usage during integration	Constantly adopted calculus & integration into their learning, infrequently adopted calculus & algebra	When writing sectional examination, learning, & assignment
4	Memorization method	Repeating learnt mathematical formulae	During rote learning
5	Final result of interdisciplinary integration	Worksheet calculation for examination purpose	During measurement & class assessment

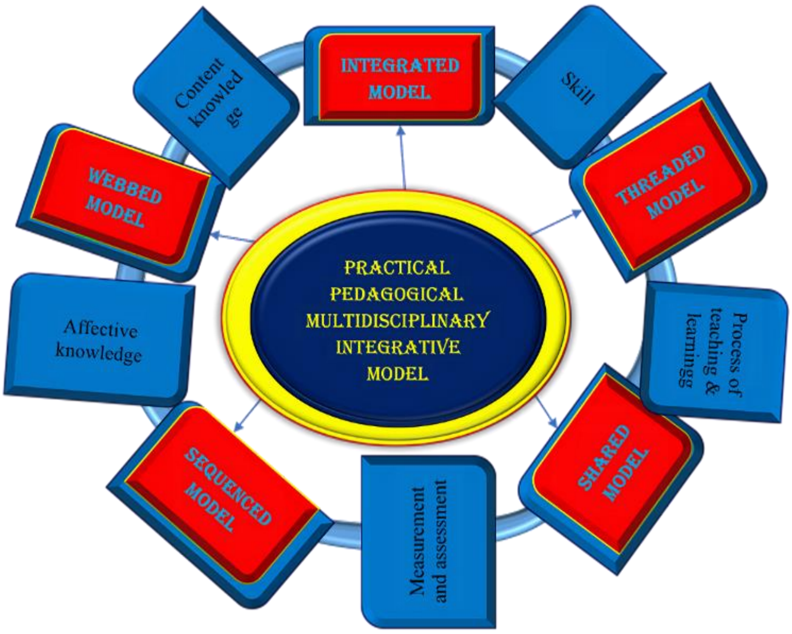

Figure 5. A practical pedagogical multidisciplinary integrative model (PPMIM) (Fasinu, 2017)

compulsory tool necessary for the academic process, which should be given a better opportunity to be applied during the process of teaching and learning. Therefore, the fact remains that problem identification, selection of the appropriate mathematical concepts to be adopted, the degree of mathematical usage and the verification of result among many others, has been a notable approach when teaching physical electronics in the school of engineering. Interdisciplinary integration is a necessity among engineering academics learning physical electronics.

Drawing on the approaches stated above coupled with the data collected and analyzed by the researchers, it could be seen that a practical pedagogical multidisciplinary integration model (PPMIM) will go a long way in resolving confusion about a suitable model for teaching physical electronics. This model was generated due to the integration of physics, mathematics and physical electronics, using the findings and the guidance from the views of other researchers like Fogarty (1991) and Kiray (2012), as reported above. A diagrammatic illustration of PPMIM model is displayed and explained in **Figure 5**.

The PPMIM is a tool that could be adopted in blending mathematics and the teaching of physical electronics together in a multidisciplinary manner. It allows the incorporation of mathematics into the learning physical electronics in a better manner, which allows the teacher to interrogate common problems, topics, sub-topics, issues, and themes by adopting two or more disciplines with sound integration strategies (Ríordáin et al., 2016). On this note, the use of two models to integrate mathematics into physical electronics has resulted in the PPMIM. Fogarty's (1991) interdisciplinary model helps to deal with the process of integrating topics and concepts across disciplines. However, there is a wide gap in leaners' affective domain and the measurement of assessment, which was absent in his model. The sequenced model sees curriculum as an entity, which is connected by rearrangement in serial order. The webbed model views a curriculum as a singular discipline, which allows departmental blending of ideas, while the threaded model is seen as a big idea, which allows linking of skills. The shared model on its part sees curriculum as a tool to bring two or more disciplines together through overlapping, and the integrated model sees curriculum as a tool that is used to view the interdisciplinary topics and concept being overlapped (Fogarty, 1991). On the other hand, Kiray's (2012) integrative model describes an integrative approach with the consideration of the following: w.r.t. skills, the curriculum is seen as the curriculum as a tool that could assist a students in blending their mathematical concepts using appropriate means of learning e.g., practical style, traditional learning, and so on. Content knowledge sees curriculum as a tool that requires learner understanding of the main discipline to be integrated. While the affective domain of students was considered as a tool that reveals students' consciousness and morale when learning mathematics integration, which eventually gives room for better result. Furthermore, measurement and evaluation should not be toyed with just because it gives room for rating the students' performances in their subjects. Lastly, the process of teaching and learning also seemed like tool for integrating mathematical concepts. All these considerations gives room for PPMIM, which remains a reliable tools for learning. In light of this, the process of integrating mathematics into physical electronics was found to be possible; however, it was found that only a few electronics undergraduate students possessed some knowledge on the integration of mathematics into physical electronics, which eventually made the blending process less practicable. In conclusion, the PPMIM framework, as suggested above, was found to be a feasible framework, although, most of the electronics engineering students did not fully have the required knowledge to integrate mathematics into physical electronics.

CONCLUSION

This study reports approaches to integrating mathematical concepts into the learning of physical electronics. It was found that electronics engineering students taking physical electronics adopted the following approaches: identification of the problems, election of the formula to adopt, integrating of the problems, synthesizing and resolving a possible outcome. Conclusively, based on all these findings, it was clearly observed that many electronics engineering students taking physical electronics experienced the need to blend mathematics with their physical electronics but lacked the necessary fundamental knowledge. In view of this, we make the strong case that the use of PPMIM will go a long way in resolving the learning challenges of integration since physical electronics involves the incorporation of different disciplines. Therefore, there is a need to consider how mathematics can best be blended or integrated with physics when learning physical electronics.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: Ethical permission was obtained from all participants and in accordance with the university requirements. The ethical protocol number for this study is HSS/0900/016M.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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