The mediating role of higher-order thinking skill in the relationship between mathematics strength and achievement in electrical and electronic engineering education

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ABSTRACT

Purpose: The paper aims to examine the casual role of higher-order thinking skills as a mediator in the relationship between students' strength in mathematics and achievement in electrical and electronic engineering education.
Design/Methodology/Approach: The study adopted a quantitative research design where random cluster sampling was used to select a total of 488 final-year students from four technical universities in Ghana. Mathematics achievement tests were used to gather data on students' higher-order thinking skills and competence in five areas of mathematics. Also, their examination results were collected from their respective universities. Mediation analysis was done using AMOS 26.
Finding: The study revealed that the positive effect of students' strengths in the five selected mathematics topics on their performance in electrical and electronic engineering education is mediated by their higher-order thinking skills.
Conclusion: The research concludes that there is a partial mediation in the relationship between students' strength in mathematics and achievement in electrical and electronic engineering education by higher-order thinking skills.
Research Limitations: It is recommended that further researchers carry out similar research with more mathematics indicators to explain more variations in achievement in electrical and electronic engineering education.
Practical Implication: Engineering mathematics curriculum developers should stress the need for mathematics, especially algebra, for the development of higher-order thinking skills to facilitate problem-solving in electrical and electronic engineering education and practice.
Contribution to Literature: This study highlights the relationship between the understanding of the concepts of specific mathematics topics, higher-order thinking skills, and achievement in electrical and electronic engineering education.

Keywords: *Achievement, Electrical and electronic engineering, Higher-order thinking skills, Mathematics strength, Mediation, Problem-solving, Structural equation muddling.*

1. INTRODUCTION

Problem-solving can be viewed as a component of higher-order thinking (HOT). Teaching HOT aims to equip students with the skills necessary to recognize and address issues in both their academic and personal lives. This includes figuring out fresh solutions to problems with which they identify themselves as well as pre-established challenges (the kind of problem solving we generally associate with education). "Being able to think" here refers to students' ability to think creatively and solve problems (Gunawardena & Wilson, 2021). Higher-order mathematics thinking (HOMT) therefore involves the use of the acquired thinking skill to recognize and think through problems and translate them into mathematical models that can be readily solved in the context of applications, analysis, synthesis, and evaluation. This is actually in the context of Bloom's Taxonomy (Rasyidi & Winarso, 2020). Higher-order thinking skills (HOTS) as an education reform concept in relation to mathematics is based on learning taxonomies such as those of Bloom, which are based on the notion that more cognitive processing is required in some types of learning and problem-solving in mathematics than others but also offer more generalized advantages (Widana, 2017). Higher-order thinking (HOT) pertains to learning and problem-solving characterized by analysis, synthesis, and evaluation, while lower-order thinking (LOT) encompasses activities with lower cognitive demands, focusing on knowledge, comprehension, and application (Heng & Ziguang, 2015). Teaching HOTS involves offering students meaningful and contextually relevant topics that have real-world applicability (Zohar & Dori, 2003). The learning activities encompass tasks such as creation, analysis, and evaluation. These activities require individuals to demonstrate logical, creative, and reflective thinking when confronted with novel issues, uncertainties, inquiries, or ethical dilemmas. To encourage students to delve deeper than the surface content of texts and establish connections with other subjects, local and global contexts, and their personal experiences and knowledge, one effective approach is to ask them deep questions (Fullan & Langworthy, 2013; Hamiloğlu & Temiz, 2012).

HOT is renowned for its strong emphasis on the cultivation of critical thinking skills. Fullan and Langworthy (2013) defined critical thinking as the ability to "think critically to design and manage projects, solve problems, and make effective decisions using a variety of digital tools and resources." In a similar vein, Trilling and Fadel (2009) characterized critical thinking as the skill to evaluate, summarize, and synthesize information. HOTS in mathematics instruction consists of nine elements: applying mathematical principles, predicting impacts, resolving problems, making decisions, operating within one's expertise, experimenting with novel approaches, engaging in divergent thinking, and employing imaginative thinking (Tanujaya, 2016).

For electrical and electronic engineers, having a solid foundation in mathematics, a broad understanding of the subject, and being able to use that knowledge and skill to solve technical problems are crucial (Qadir, Yau, Imran, & Al-Fuqaha, 2020; Smith-Moyler & Grooms, 2022). This is consistent with the fact that mathematics is used in every branch of electrical and electronic engineering to undertake quantitative analyses of engineering systems. Therefore, in the 21st century, mathematics plays an important role in engineering education (Uysal, 2012), and in addition, HOTS is crucial for problem-solving in mathematics and engineering education (Chinedu, Olabiyi, & Kamin, 2015; Isharyadi & Juandi, 2023; Yang, 2015).

According to statistics from the 2011 Trends in International Mathematics and Science Study (TIMSS), thinking ability among Ghanaian students is rated as being below average. Students from Ghana can only practice on problems requiring minimal critical thinking skills (questions that only require skills such as knowing or recall) (Bonyah & Clark, 2022). Even though Ghanaian teachers performed rather well across the majority of the teacher preparation categories examined by the TIMSS study, this did not translate into improved student achievement. It is advised that researchers give attention to studying their students' high-order thinking levels in light of this (Wardat, Belbase, & Tairab, 2022). The system in place to help engineering students study engineering mathematics still doesn't appear to be doing enough to improve students' capacity for analytically and critically applying their mathematical knowledge and abilities.

Though some empirical studies were conducted in this area of study (*see* Section 2.3), they were directed towards improving the teaching and learning of mathematics and engineering. However, we are still left with a gap in the literature. There is a dearth of research that systematically examines the relationships and interactions among the three: HOT, mathematical strength, and achievement in electrical and electronic engineering education, as well as literature that provides a thorough overview of their interconnection.

The objective of this paper is to investigate the causal role of HOTS. The objective of this paper is therefore to examine the casual role of HOTS as a mediator in the relationship between mathematics strength and achievement in electrical and electronic engineering education, using problem-solving that involved application, analysis, synthesis and creating in five selected topics in mathematics: algebra, functions, trigonometry and complex numbers, calculus and differential equations, and probability as a measure of HOTS. The acquisition of knowledge pertaining to the interconnections and interplay among these three elements is expected to contribute significant insights to the pedagogical aspects of electrical and electronic engineering within higher education. In some institutions, various mathematics learning supports such as tutorial services, counseling, and learning management

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education are given to mathematically weak students, and this may be recommended where the study reveals that it is necessary (Gallimore & Stewart, 2014; Hillock, Jennings, Roberts, & Scharaschkin, 2013; Rylands & Shearman, 2018). The outcome of this study will hasten the process of understanding the essence of applying and translating mathematical knowledge and HOTS into electrical and electronic engineering education through problem-solving. We therefore examine the problem-solving framework that underpins this study in Section 2.

2. REVIEW OF LITERATURE

2.1. Theory of Problem Solving in Mathematics

Mathematics education is basically problem-solving, and it is the initial stage of engagement in HOT processes. Various definitions of problem-solving in technology and engineering include the following: Problem-solving is defined as the process whereby a plan of action is designed, analyzed, and put into practice in order to respond to an open-ended query or realize an objective (López-Pérez, Cardona, Lora, & Abad, 2016). Problem-solving involves the ability to recognize and define problems, generate various potential solutions, choose and implement the most suitable ones, and assess the results (Raftery, Steinke, & Nickerson, 2010). Problem-solving is a systematic process that involves identifying a problem, examining the information provided, understanding what needs to be solved, suggesting solutions, evaluating the results, and critically evaluating the results (Alkhatib, 2019). Techniques for identifying solutions to mathematical problems are termed heuristics. A world-renowned Hungarian mathematician, George Polya (1887–1985), is credited with five classic works on problem-solving. These publications are concerned with the application of mathematical heuristics (Alexanderson, 2000; Schoenfeld, 1987). The problem-solving skills and ideas shown below will be used to identify the most significant ones in the problem-solving theory found in George Polya's masterpieces.

Mathematical problem-solving improves both one's ability to build a wide variety of complicated mathematical structures as well as one's ability to solve a wide variety of real-world situations (Bayat & Tarmizi, 2012; Tarmizi & Bayat, 2012). In addition, solving problems helps people adapt to changes and unforeseen circumstances in their jobs and other spheres of life. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 2016 underscored the importance of cultivating 21st-century competencies, which include problem-solving, critical thinking, creativity, and decision-making skills, in educational systems across different countries (Kulnazarova & Ydesen, 2016).

Problem-solving moves beyond the dimensions of teaching and learning mathematics, so that the influence of mathematics in engineering education and in the world around them will be experienced by students (Douglas, Koro-Ljungberg, McNeill, Malcolm, & Therriault, 2012). Though other suggested viable abilities may be added in consideration of the successful application of learning and problem-solving skills, these necessary methods and skills for problem-solving are essential and are considered in an effective implementation of learning skills (Pólya, 1945) stated the following four-step technique of problem solving, and these include:

1. Understanding the problem: Without a clear understanding of the problem, it cannot be solved. What is known or not known? Is enough information available, or is further information needed? Which word means what?
2. Making a plan: The approach to the problem. Potential strategies: (a) Make drawings; use variables and give names to variables or unknowns; (c) Do it systematically; (d) solve an easier problem of its kind; (e) Guess and check; trial and error; guess and test (guessing is accepted); (f) Search for any patterns; (g) compile a list.
3. Executing the plan: If the plan doesn't seem to be working, start over and try a fresh technique. The first approach usually fails. You shouldn't become disturbed just because a plan doesn't work. It doesn't indicate that you acted incorrectly. You actually accomplished something. Part of the process of elimination is figuring out when a technique doesn't work.
4. Looking back: Did you respond to the question? Did you have a reasonable result? Is there an alternative approach that might make it easier to solve the problem?

Problem-solving is significant in today's mathematics, scientific, and engineering fields because it not only helps students learn the knowledge and skills needed to solve problems, but also helps them develop their critical thinking abilities (Hmelo, Guzdial, & Turns, 1998). Methods of problem solving are thus regarded as factors affecting the level of mathematics achievement of the students (Lessani, Yunus, Bakar, & Khameneh, 2016). And it is utilized to solve problems that emerge in engineering education and practice. Thus, problem solving goes beyond the mathematics lecture room (Douglas et al., 2012). Again, the three: mathematical thinking, HOT, and problem solving in an engineering learning environment, cannot be separated (Ghasempour, Kashefi, Bakar, & Miri, 2012; Hamilton, Lesh, Lester, & Brilleslyper, 2008; Moore, Miller, Lesh, Stohlmann, & Kim, 2013).

2.2. Theoretical Connection among Mathematics, Higher-Order Thinking, and Electrical and Electronic Engineering

Mathematics, higher-order thinking, and electrical engineering are interconnected disciplines that play a crucial role in advancing technology and innovation (Chang, Hwang, Chang, & Wang, 2021). The relationship among these areas is symbiotic, with each field complementing and enhancing the others in various ways (McGilly, 1994). In this note, we will explore how mathematics and higher-order thinking are fundamental to the practice of electrical and electronic engineering and how this relationship drives progress in the field.

Mathematics is the foundation of all engineering disciplines, including electrical engineering (Maciejewski et al., 2017). The utilization of mathematical disciplines such as calculus, linear algebra, differential equations, and complex analysis is vital in the process of formulating and resolving electrical engineering quandaries. For example, when designing electrical circuits, analyzing signals, or optimizing system performance, engineers heavily rely on mathematical tools to represent and manipulate electrical phenomena (Seborg, Edgar, Mellichamp, & Doyle III, 2016).

Electrical engineering is not just about applying mathematical formulas; it also requires higher-order thinking skills to conceptualize, design, and solve complex problems (Barak, 2013). Higher-order thinking involves critical and analytical reasoning, creative problem-solving, and the ability to think outside the box. Electrical and electronic engineers often encounter challenges that demand innovative solutions, and higher-order thinking allows them to devise novel approaches to address these issues effectively. The practical application of mathematical principles in electrical engineering is diverse and far-reaching. Some common examples include the following (Dastres & Soori, 2021; Hayes, 2022; Kim, 2020; Murray-Smith & Johansen, 2020):

2.2.1. Circuit Analysis

Electrical engineers use mathematical techniques such as Kirchhoff's laws, mesh and nodal analysis, and Laplace transforms to analyze and design electronic circuits.

2.2.2. Control Systems

Mathematical modeling and control theory are employed to design and analyze systems that automatically control various processes, such as in robotics or industrial automation.

2.2.3. Signal Processing

Mathematics is vital in the study of signals, which can represent data, speech, images, etc. Engineers use techniques like Fourier transforms and digital signal processing to analyze and manipulate signals.

2.2.4. Communication Systems

Mathematics plays a central role in designing communication systems, coding schemes, and error-correction algorithms, which are crucial for modern telecommunications.

The synergy between mathematics, HOT, and electrical engineering has been the driving force behind significant technological advancements. As our understanding of mathematics has grown, so has our ability to model and optimize complex electrical systems. This, in turn, has led to the development of more efficient and innovative technologies (Coccia, 2005). For example, the use of HOT has been instrumental in the miniaturization of electronic devices, the improvement of renewable energy systems, and the design of sophisticated integrated circuits (Peftitsis & Mavroudi, 2022). Advanced mathematical techniques, such as optimization algorithms and machine learning, have revolutionized signal processing and data analysis, enabling breakthroughs in fields like image and speech recognition, as well as artificial intelligence (Deng, 2018).

In conclusion, the relationship among mathematics, higher-order thinking, and electrical engineering is fundamental to technological progress. Electrical engineers leverage mathematical principles and apply HOT to solve real-world problems and develop innovative solutions. This interplay between disciplines continues to shape the landscape of electrical engineering and drive advancements in technology that benefit society as a whole.

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2.3. Review of Previous Studies

There have been a number of research studies across the globe relating to 1. Strength in mathematics and engineering education, 2. Mathematics and HOTS, and 3. The utilization of HOTS in engineering education is a valuable opportunity for Ghanaian educational policymakers to enhance the quality of education.

Nanayakkara and Peiris (2016) employed partial least-square structural equation modeling to establish a relationship model connecting students' mathematics performance with their overall academic achievement in engineering programs at the University of Moratuwa, Sri Lanka. Their findings indicated that mathematics performance was notably correlated with the academic performance of students in chemical and process engineering programs. In a separate study, these researchers also identified a correlation between students' mathematics performance in Level 1 and their academic performance in Level 2, regardless of their particular engineering field within the university's Faculty of Engineering.

Similarly, many authors have researched and concluded that students' knowledge of mathematics positively affects their performance in engineering education (Abaigar & Varela, 2021; Bischof, Zwölfer, & Rubeša, 2015; Derr, Hübl, & Ahmed, 2018; Field, 2007; Lee & Lee, 2009).

On the relationship between mathematics strength and HOTS, Tanujaya, Mumu, and Margono (2017) studied whether HOTS were related to academic achievement in mathematics. They found that there was a strong positive correlation between HOTS and grade point average in 41 undergraduates who had completed 120 credits in mathematics education. Similar to Dani, Pujiastuti, and Sudiana (2017); Durachman and Cahyo (2020); Cahyaningsih and Nahdi (2021); Hilmi and Dewi (2021) and Riyadi and Fathoni (2022), who used realistic mathematics education (RME) to enhance students' skills, particularly in mathematics in relation to HOTS, their findings demonstrated that students in their experimental class had better creative thinking and mathematical connections than those who received conventional mathematics instruction.

With studies on the relationship between HOTS and engineering education, Heong et al. (2012) conducted a need analysis to examine the learning requirements of HOTS for idea generation among technical students at the University Tun Hussein Onn Malaysia (UTHM). They gathered insights from experienced academic staff in the fields of civil engineering, electrical and electronic engineering, and mechanical engineering. The research findings suggested that there is a necessity for students to acquire HOTS abilities to effectively tackle the challenges associated with generating innovative ideas. Shuker (2021) also researched HOT and its relation to engineering thinking in Grade 2 intermediate students from Baghdad Education/Al-Karkh/3, and concluded that there is a positive relationship between HOT and geometric thinking. More researchers also concluded that there is a positive relationship between HOTS and engineering (Ahern, O'Connor, McRuairc, McNamara, & O'Donnell, 2012; Asok, Abirami, Angeline, & Lavanya, 2016; Sharma, Murugadoss, & Rambabu, 2020; Ubaidillah, Marwoto, Wiyanto, & Subali, 2022). We noticed that the existing literature a lacks of comprehensive research on the relationships between HOTS, mathematics achievement, and academic achievement in engineering. The proposed framework for the study is indicated in Subsection 2.4.

2.4. Conceptual Framework for the Study

A conceptual framework is a set of principles and ideas extracted from relevant fields of inquiry that is used to organize and structure a subsequent presentation (Imenda, 2014). It is also defined as a diagrammatic presentation that displays the relationship between dependent and independent variables (Haenlein & Kaplan, 2004). Based on the results reported in the literature, a conceptual framework and a group of hypotheses were extracted and developed for the current study, as shown in Figure 1.

From a survey of the relevant literature, it was found that there are no studies investigating the mediating effects of higher-order thinking in the relationship between students' ability in mathematics and their achievements in courses of study, typically in electrical and electronic engineering education in the universities. The study was therefore conducted in order to fill this clear gap in the literature. It was done by carefully studying the variables that influence the effects of students' ability to understand the concepts of five important engineering mathematics topics on their achievements in electrical and electronic engineering education. The study therefore hypothesized that:

- H_{11}: Mathematics strength has a positive direct effect on achievement in electrical and electronic engineering education

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- H_{12}: Mathematics strength has a positive indirect effect on achievement in electrical and electronic engineering education via higher-order thinking in mathematic

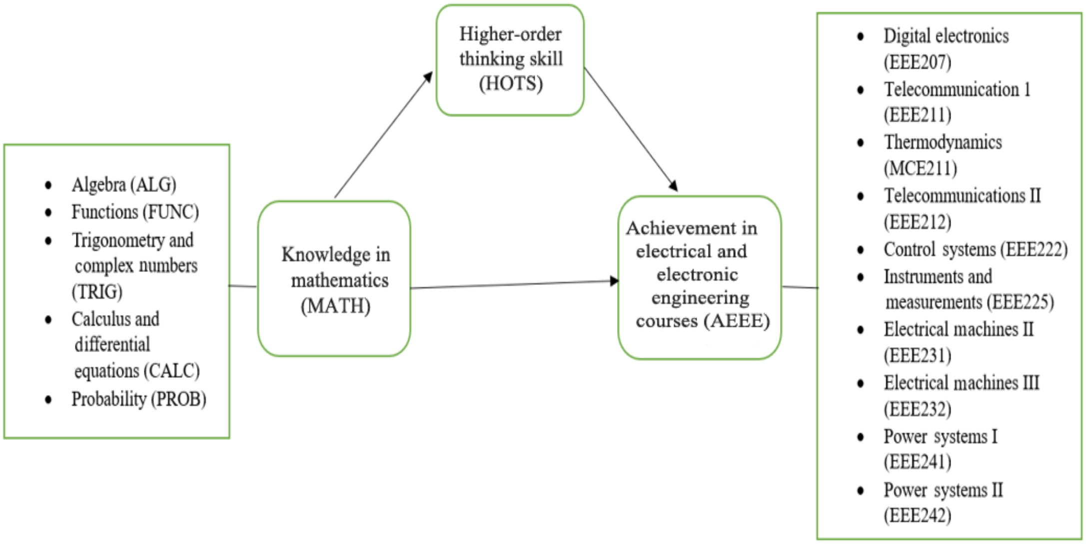

Figure 1. The mediation model for the study: The influence of mathematics on electrical and electronic engineering education.

3. METHOD

3.1. Research Design and Sample

The quantitative descriptive design was used with the relational survey model. The rational survey model aims to measure the presence and degree of variation between two or more variables (Karasar, 2008). We aimed to describe the effects that students' drawbacks in mathematics have on their main electrical and electronic engineering subjects without any attempt to change or influence them.

The subjects of the study are the 2021-2022 final year Higher National Diploma (HND) electrical and electronic engineering students in the ten technical universities (TUs) in Ghana who have already completed their engineering mathematics courses over their first four semesters and make up the population of interest for this study. The HND is an academic higher education credential in Ghana and numerous other nations that equips students with skills and knowledge for middle-level professional roles. The group under consideration comprises individuals who have previously pursued their education in both senior high schools and pure technical schools. Four TUs were randomly selected from the ten. Second-year HND electrical and electronic students at Cape Coast Technical University (CCTU) who had just completed their fourth semester were selected to test the MAT instrument. We anticipated that the data from the three technical universities would be homogeneous. This is as a result of a common entry requirement and syllabus for the HND electrical and electronic engineering program. Within the TUs that were randomly sampled, a convenient sampling technique was used to get a sample total of 488 students. A convenient sampling procedure was adopted within the selected TUs. That is, those who turned up for all four MAT I and II sittings. These are 281 students from Accra Technical University (ATU); 54 from Cape Coast Technical University (CTU); 123 from Ho Technical University (HTU); and 30 from Wa Technical University (WTU), making the total sample for the study. These samples were, however, found to be approximately proportional to the numbers offering HND electrical and electronic engineering studies in the institutions.

3.2. Instrumentation

De Lange's pyramid is redesigned to measure students' mathematics strength in three dimensions: domain of knowledge (algebra, functions, trigonometry, calculus, and probability); levels of mathematics difficulty (low to high); and cognitive level (knowledge, comprehension, application, and HOT) (De Lange, 2007). The five mathematics content areas (domain of knowledge) were purposefully selected from the HND electrical and electronic engineering curriculum in Ghanaian TUs. The test items for the MAT were carefully planned to ensure that the level of difficulty was not above that of the content of the HND syllabus.

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The Mathematics Achievement Test (MAT) used for this research had two types: the subjective type (MAT I) and the objective type (MAT II). Both MAT I and MAT II were both made up of five sections, A to E, covering the areas of Algebra, Functions, Trigonometry and Complex Numbers, Calculus and Differential Equations, and Probability, respectively. MAT I consisted of test items in each section that measured students' HOTS (analysis, evaluation, and creativity). MAT II consisted of twenty (20) objective test items in each section, covering the course content for the study in the six levels of the cognitive domain according to the Bloom Taxonomy (Kartikasari, Kusmayadi, & Usodo, 2017). Test items were knowledge, comprehension, and higher-order thinking. Table 1 shows the test item specifications for MAT II.

Table 1. Achievement test item specification in MAT II.

Domain of knowledge	Cognitive level				Total
	Knowledge	Comprehension	Applications	HOT	
Algebra (ALG)	5	5	5	5	20
Functions (FUNC)	5	5	5	5	20
Trigonometry and complex numbers (TRIG)	5	5	5	5	20
Calculus and differential equations (CALC)	5	5	5	5	20
Probability (PROB)	5	5	5	5	20
Total	25	25	25	25	100

3.3. Data Collection Procedure

Because of the volume of the test, MAT II was administered on three different occasions at ATU, CCTU, HTU, and WTU under standard examination conditions. The many items in the MAT ensure repeated measurements in the cognitive domain, thus reducing the effect of using multiple choices in the measurements. We were also motivated by the positive impact multiple-choice question authoring and regular participation have on students' learning (Riggs, Kang, & Rennie, 2020).

Secondary data from university examination centers, specifically the raw scores for each student's core engineering subjects during their third and fourth semesters of study, was collected. Subsequently, we entered every student's results into the Statistical Package for Social Sciences (SPSS) version 26.0 accordingly and employed Analysis of Moment Structures (AMOS) to formulate a structural equation model, allowing us to assess our proposed model. AMOS, an extension of the Generalized Linear Model (GLM), permits simultaneous testing of a group of regression equations. Structural equation modeling enables the concurrent estimation of several independent multiple regression equations, integrating latent variables and accounting for measurement errors throughout the estimation process (Hair, Anderson, Tatham, & Black, 1998).

3.4. The Covariance-Based Structural Model

The CB structural model employed in this study consists of two unobserved latent variables: students' knowledge in mathematics, which measures mathematics strength, MATH, and achievement in electrical and electronic engineering, AEEE, which are exogenous and endogenous reflectively measured constructs, respectively. We reflectively measured the MATH construct because students' mathematics strengths manifested in the areas of the five mathematics topics (not exhaustive) selected for the study, and these are assumed to be applied to solving electrical and electronic engineering problems, also measured reflectively by the ten engineering courses in AEEE. The effect was then mediated by HOTS scores.

Cronbach alpha was determined for each of the MAT indicators as the initial stage in determining the reliability and internal consistency of the items. A confirmatory factor analysis to the look at the factor structure followed the reliability test. With the help of standard absolute fit indices, the entire model fit was evaluated. Chi-square, the comparative fit index (CFI), Turker-Lewis's index (TLI), the incremental fit index (IFI), the root mean square error of approximation (RMSEA), and the standardized root mean square residual (SRMR) were all used to measure fit indices.

3.5. Mediation Analysis

In this study, a mediation model was created, as shown in Figure 2. A and B, respectively, denote the path coefficients from MATH to HOTS and HOTS to AEEE. The path coefficient from MATH to AEEE, or c', illustrates the

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direct impact of MATH on AEEE. This model includes one specific indirect effect (SIE). The outcome variable resulting from the product of *a* and *b* represents the indirect effect of MATH on AEEE, through HOTS (SIE). Consequently, SIE+*c*', the overall effect of MATH on AEEE is quantified. This process model evaluation is termed a mediation study, allowing researchers to understand the meaning of 'a predictive variable exerts its effect on an outcome variable' (Preacher, Rucker, & Hayes, 2007). It is essential to pay adequate attention to the mediation effect in a model; otherwise, the relationship between the two variables of interest may not be fully taken into account (Raykov & Marcoulides, 2006).

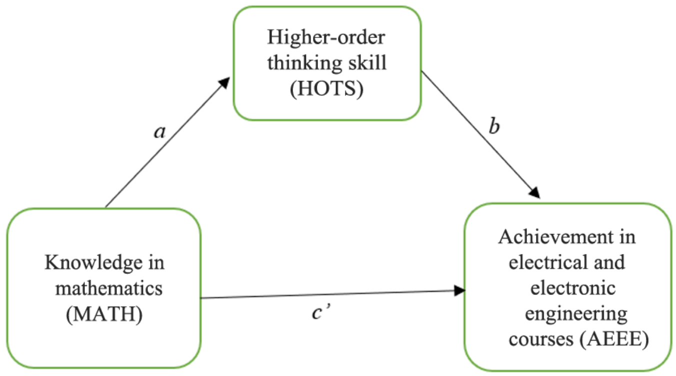

Figure 2. Mediation model.

While there are many ways to estimate the size of an indirect influence, the causal steps technique from (Baron & Kenny, 1986) has been the most popular (Hayes, 2009; MacKinnon, Lockwood, & Williams, 2004). Nevertheless, the method has been criticized by some researchers for its low statistical power (Fritz & MacKinnon, 2007; Hayes, 2009), and it can be comfortably applied only to simple mediation models (Preacher et al., 2007). Therefore, we conducted (Baron & Kenny, 1986) mediation analysis on our simple mediation model hypothesized in Figure 2. This method relies on the assumption that the product of *a* and *b* follows the normal distribution, which can be challenging for researchers to achieve (Bollen & Stine, 1990; Preacher et al., 2007). Hence, for this study, we utilized the bootstrapping technique (Bollen & Stine, 1990; Hair Jr & Fávero, 2019; Hayes, 2009; Preacher et al., 2007). The following tests and analyses are therefore presented in the next section: descriptive statistics, the proposed structural model, reliability, convergent validity, and discriminant validity tests, as well as the measurement model test, test of the hypotheses, and analysis of the results.

4. RESEARCH FINDINGS

4.1. Descriptive Analysis

The research model in Figure 1 hypothesizes that a student's ability in mathematics (MAT) has an effect on his or her achievement in electrical and electronic engineering education (ENG), and this effect is mediated by HOTS.

The mean, standard deviations, skewness, and kurtosis values of the MATH and HOTS are presented in Table 2. The means range from 45.36 to 58.36, indicating that the electrical and electronic engineering students who took part in the study exhibited performance that was above the average score of 50% in the MAT tests, except in Probability (score = 45.36).

Table 2. Mean, standard deviation, skewness and kurtosis of the MAT variables.

Variable	Mean	SD	Skewness	Kurtosis
ALG	55.89	13.608	0.038	0.286
FUNC	58.14	12.045	0.047	0.197
TRIG	58.36	11.163	-0.229	1.378
CALC	55.11	11.874	-0.562	0.746
PROB	45.36	13.455	-0.122	0.537
HOTS	42.61	15.871	0.086	0.036

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Their HOTS was also below average (mean score = 42.61). The MAT scores appeared to be rather well distributed around the mean, according to the magnitude of the standard deviations (11.163 to 13.608). The skewness and kurtosis results showed that the corresponding subscale distributions do not deviate significantly from the normal distribution (Tabachnick & Fidell, 2013). Therefore, the indicators were seen as reasonably univariate normal.

4.2. Measurement and Structural Model

SEM requires that the data exhibit multivariate normality, which is an essential prerequisite for analyzing this dataset (McDonald & Ho, 2002). In the present study, an evaluation was conducted on the data to determine its adherence to the assumption of multivariate normality. While all individual variables were found to be normally distributed, the multivariate kurtosis value yielded a critical ratio exceeding 5.00 (c.r. = 6.798), indicating that the data exhibited non-normality in a multivariate context (Nevitt & Hancock, 2001; Yuan, Bentler, & Zhang, 2005). This may be misleading for the researcher to reject the correct model (Fan, 1998; Lei & Wu, 2007). Given this situation, it is recommended by Byrne (2016) that researchers "correct the test statistic rather than use a different mode of estimation". Consequently, to estimate the chi-square and standard error, we employed the Bollen-Stine bootstrapping technique, which can provide valuable insights into how the test statistic behaves when dealing with non-normal data (Bollen & Stine, 1992). Analyses were performed to assess the internal consistency of the items, specifically calculating the Cronbach alpha coefficients for the constructs, MATH and AEEE, which were 0.875 and 0.915, respectively. All of the indicators' Cronbach alpha values were greater than 80, indicating that the test instrument's internal consistency was adequate (Nunnally & Bernstein, 1994).

By considering their loadings, square multiple correlations, composite reliability, and average variance extracted (AVE), the indicators of MATH and AEEE were assessed for convergent validity (Fornell & Larcker, 1981). Table 5 presents the item loadings, composite reliability (CR), and average variance extracted (AVE). The recommended minimum values for item loadings are 0.7 (Barclay, Higgins, & Thompson, 1995; Chin, 1998; Hair, Black, Babin, & Anderson, 2010); composite reliability is 0.7 (Nunnally & Bernstein, 1994); and AVE is 0.5 (Fornell & Larcker, 1981).

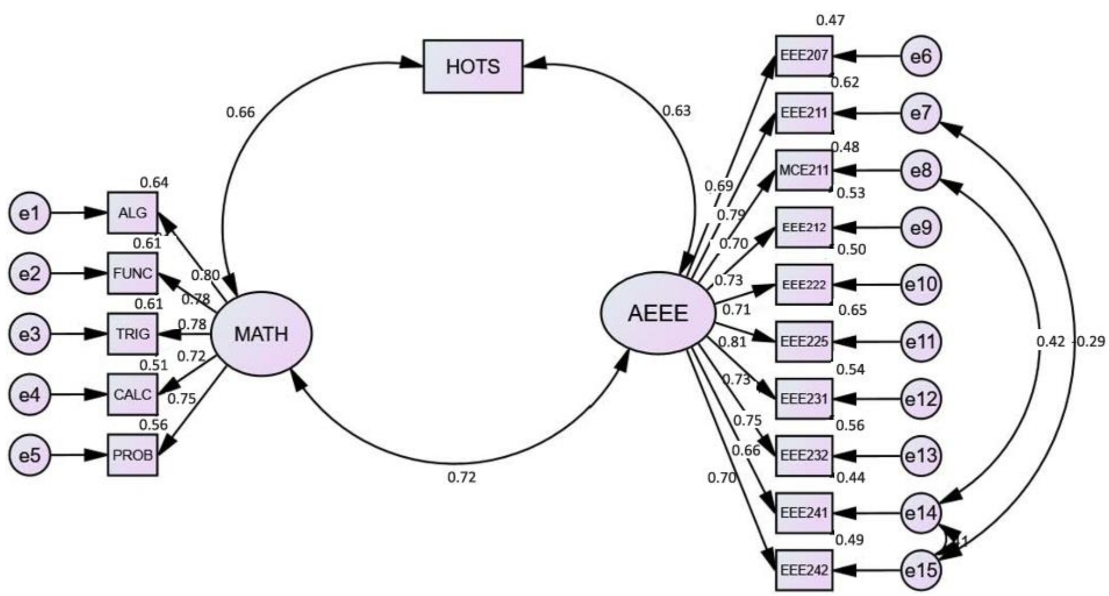

Figure 3. Measurement model.

According to the findings, all loadings were discovered to be higher than the suggested cut-off threshold. The square multiple correlations for these variables (Table 5) were all greater than .3.6, signifying that all the variables fit appropriately with the other variables in their constructs.

All items, except two, were included for further analysis, and each construct's composite reliability was calculated, as shown in Table 5. Both constructs met the recommended minimum value of .7, indicating good reliability. Additionally, convergent validity was assessed through the average variance extracted (AVE) for each factor. The findings in Table 5 indicated that the AVE values for both constructs were above .50, satisfying the convergent

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validity criterion. The results suggested that the observed variables of each construct were highly correlated and reliable. To establish discriminant validity, the inter-construct correlations needed to be smaller than the square root of the AVE for each construct. The results in Table 3 showed that the results were discriminant valid because the correlation between each construct and the other construct was less than the square root of its AVE. This result confirmed the achievement of discriminant validity, demonstrating that each construct and the mediator were distinct from one another according to the discriminant validity analysis.

Table 3. Inter-construct correlation and square root of average variance extracted.

Construct	AEEE	MATH
AEEE	(0.728)	
MATH	-0.717**	(0.767)

Note: N=488. The diagonal elements in parenthesis show the square roots of the AVEs. MATH, knowledge in mathematics; AEEE, Achievement in electrical and electronic engineering education, **p<.01.

The research model represented in Figure 2 was evaluated using the SEM approach using AMOS 26.0 (Arbuckle, 2012). Figure 3 illustrates a measurement model in which 16 measured variables yielded a Bollen-Stine $\chi^2$of 285.777 with 75 degrees of freedom after modification. The resulting model had to be modified by removing two indicators of AEEE with correlating errors, which was done with the aid of the modification indices (Kang & Ahn, 2021). Table 4 shows a summary of the results usually used as measures of model fit and their corresponding recommended levels of acceptable fit. All the values, except for the χ^2, met the suggested thresholds for satisfactory fit. Hair, Hult, Ringle, Sarstedt, and Thiele (2017) observed that, in the case of large sample sizes, the χ^2 statistics tend to show significant differences. For this reason, the relative χ^2 (χ^2/df) was used, with 5 or less, recommended as acceptable fit between the sample data and hypothetical model. From the values of the various model fit indices presented in Table 4, we conclude that the research model fits fairly well.

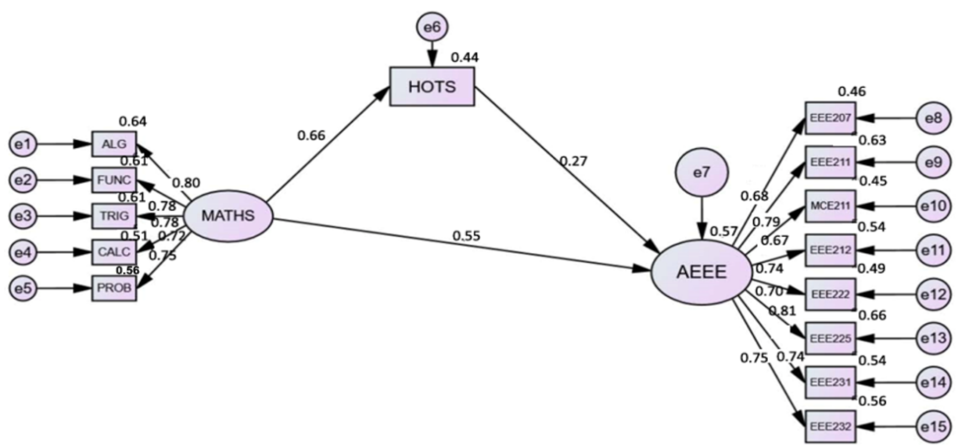

Figure 4. Hypothesized model of the relationship among MATH, HOTS and AEEE.

Table 4. Model fit indices for the hypothesized model.

Model fit indices	Value	*Recommended guideline
Bollen–Stine χ^2	285.777, p=0.00	Not significant
χ^2/df	3.810	<5
TLI	0.933	≥0.90
CFI	0.945	≥0.90
IFI	0.945	≥0.90
RMSEA	0.076	<0.08 (Acceptable fit)
SRMR	0.0413	<0.05

Note: *Hair et al. (2017).

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Table 5. Constructs and their psychometric properties.

Construct		Observed variable	Test of significance				Factor loading (Std)	Indicator reliability (SMC)	Comp rel. (CR)	Conv validity (AVE)
			Unstd.	SE	*t*-Value	*p*				
MATHS	HOTS		1.039	0.072	14.377	***	0.662	0.438		
HOTS	AEEE		0.169	0.031	5.467	***	0.629	0.396		
MATHS	AEEE		0.522	0.059	8.838	***	0.718	0.516		
MATHS		ALG	1.077	0.061	17.587	***	0.802	0.643	0.874	0.588
		FUNC	0.932	0.055	17.046	***	0.782	0.612		
		TRIG	0.861	0.051	16.895	***	0.779	0.607		
		CALC	0.841	0.053	15.741	***	0.716	0.513		
		PROB	1.000				0.751	0.564		
AEEE		EEE207	1.000				0.700	0.491	0.907	0.530
		EEE211	0.917	0.058	15.700	***	0.772	0.595		
		MCE211	0.957	0.064	14.953	***	0.709	0.503		
		EEE212	0.746	0.050	15.025	***	0.729	0.531		
		EEE222	1.163	0.078	14.920	***	0.713	0.508		
		EEE225	0.922	0.055	16.617	***	0.807	0.651		
		EEE231	0.862	0.058	14.926	***	0.728	0.529		
		EEE232	743	0.049	15.309	***	0.741	0.550		

Note: *N*=488. *MATH*, knowledge in mathematics; *HOTS*, higher-order thinking skill; *AEEE*, Achievement in Electrical and Electronic Engineering Education, *AVE*, average variance extracted, *SMC*, squared multiple correlation; *Std*, standardized; *Unst*, unstandardized; *SE*, standard error. ****p*<.001.

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4.3. Mediation Analysis

The study was an assessment of the mediating role of HOTS in the relationship between MATH and AEEE. To have insight into the effect of the mediator (HOTS), we reported: 1. direct effect of MATH on HOTS (the mediator); 2. direct effect of HOTS on AEEE; 3. direct effect of MATH on AEEE in the presence of HOTS; 4. indirect effect of MATH on AEEE through HOTS; and 5. Total effect of MATH on AEEE.

Figure 4 illustrates the standardized path estimates and *R*-square of the hypothesized model. Following Baron and Kenny (1986) mediation analysis, the results revealed a significant positive indirect effect of MATH on AEEE (*SIE* =.176, *p* =.000). This result of the indirect effect supports the research hypothesis, H_{12}. This indirect effect was broken down into two direct significant paths: the direct effect of MATH on HOTS was significant at 95% confidence level (a=.662, t =17.421, p =.000) and the direct effect of HOTS on AEEE (b = .266, p =.000). Moreover, in the presence of HOTS as a mediator, the direct effect of MATH on AEEE was also found significant (c'=.552, p = 001), and this was in support of H_{12}. Hence, HOTS partially mediated the relationship between MATH and AEEE. AMOS estimated confidence intervals for these paths that did not include zero, confirming that the paths were significant. Mediation analysis summary has been presented in Table 6.

Table 6. Mediation analysis summary.

	Relationship		**Effect**	***p*-value**	**Confidence interval**		**Remark**
					Lower bound	**Upper bound**	
1.	Direct	MATH→HOTS	0.662	0.000	0.583	0.733	Sig. direct effect
2.	Direct	HOTS→AEEE	0.266	0.000	0.164	0.356	Sig. direct effect
3.	Direct	MATH→AEEE (+HOTS)	0.552	0.001	0.461	0.649	Sig. direct effect
4.	Indirect	MATHS→HOTS→AEEE (SIE)	0.176	0.000	0.115	0.235	Partial mediation
5.	Total	SIE + c'	0.728	0.000	673	0.778	Sig. total effect

Note: N=488. MATH, knowledge in mathematics; HOTS, higher-order thinking skill; AEEE, Achievement in electrical and electronic engineering education; Unst, unstandardized; SE, standard error.

The coefficients of the unstandardized path and their corresponding *t*-values for their relationships hypothesized in the model are reported in Table 5. It was found that MATH had both direct and indirect positive impacts on AEEE. MATH had a significant positive direct relationship with AEEE (β = .522, p < .001), where this relationship was mediated by HOTS. Thus, MATH had a positive and significant relationship with HOTS (β = 1.039, p < .001), and HOTS also had a positive and significant relationship with AEEE (β = .169, p < .001) with an *R*-square of .438. AEEE was the only endogenous variable that was tested in the model. It was therefore found to be significantly determined by MATH and HOTS, resulting in an *R*-square of .570. The former means that students' ability in mathematics explained 43.8% of the variance in higher-order thinking, whereas the latter means both students' knowledge in mathematics and higher-order thinking skills explained 57.0% of the variation in achievement of electrical and electronic engineering education. Again, the SPSS AMOS results in Table 5 also showed significant effects of all the indicators on the constructs (*p* < .001), indicating that generally, all five areas of knowledge in mathematics play a significant role in explaining the variation in achievements in the eight electrical and electronic engineering courses. Algebra was found to have the most significant influence (β = 1.077, p<.001) on electrical and electronic courses, with EEE222 being mostly affected (β = 1.163, p<.001). The mediating role of students' HOTS in obtaining their results in engineering courses has been analyzed in the next section.

5. DISCUSSION

The study investigated the casual role of HOTS as a mediator on the relationship between mathematics strength and achievement in electrical and electronic engineering education, using problem solving that involved application, analysis, synthesis and creating in five selected topics in mathematics: algebra, functions, trigonometry and complex numbers, calculus and differential equations, and probability, as a measure of HOTS. Achievement was made up of achievements in eight influential electrical and electronic engineering core courses (EEE207, EEE211, MCE211, EEE212, EEE222, EEE225, EEE231 and EEE232) defined in Figure 1. These courses were taken after the students had completed the course content for the five mathematics topics considered. The results of the study showed that there is a collective positive effect of students' strengths in the five selected mathematics topics on their performance in electrical and electronic engineering education, and this effect is mediated by their high-order thinking skills.

The study suggests that knowledge of mathematics contributes both directly and indirectly to explaining the variance in achievement in electrical and electronic engineering education. This is in agreement with Qadir et al. (2020), who assert that the core of knowledge, the extent of exposure to mathematics, and the capability to apply the knowledge to solve engineering problems are important skills for electrical and electronic engineering. The study also revealed that higher-order thinking partially mediated the effect of students' knowledge of mathematics on their achievement in engineering education. The results of the study can be discussed from two perspectives: theoretical implications and practical implications.

5.1. Theoretical Implications

The literature suggests that critical thinking is HOT (Pretorius, Van Mourik, & Barratt, 2017; Saputri, Rinanto, & Prasetyanti, 2019). In other words, training students in HOT promotes critical thinking among them, and vice versa. Transfer of learning, which is essential in 21st-century engineering education, is facilitated by HOTS. The results of the study therefore support the theory that mathematics has a vital role in fundamentals of engineering education for 21st-century engineers (Uysal, 2012). And this is powered by higher-order thinking skills, or critical thinking.

The mathematical problem-solving thinking process of Pólya (1945) does not only facilitate the acquisition of knowledge and abilities to solve the problem, but it goes further in helping to increase reasoning skills and thus HOTS among students. Problem-solving techniques are therefore seen as crucial to raising pupils' mathematics achievement levels (Lessani et al., 2016) and consequently for better achievement in electrical and electronic engineering education. Students who are trained with Pólya's framework of problem solving will therefore increase HOTS and consequently be more successful in their engineering education.

5.2. Practical Implications

It is crucial to study the factors that significantly affect the academic achievement of students in all disciplines in order to find solutions to challenging situations that adversely affect the successful implementation of particular programs. The students, lecturers, and curriculum developers all play significant roles in ensuring successful impact of electrical and electronic engineering education in Ghanaian Technical Universities on the energy sector and the national development as a whole. By carefully analyzing the findings of this study in relation to Bonyah and Clark (2022)'s conclusion that students from Ghana can only practice on problems requiring minimal critical thinking skills (questions that only require skills such as knowing or recall, the implication here is that all three: students, lecturers, and curriculum developers, have a collective responsibility to improve the HOTS of the HND students. By doing so, the partial mediation of HOTS revealed by this study would better enhance the understanding of electrical and electronic engineering in technical universities. Ignoring the training of electrical and electronic engineering students in HOTS will have a devastating effect on the achievement of electrical and electronic engineering education. The research findings and discussions lead us to the conclusion in the next section.

6. CONCLUSION

From the research findings and discussion, we can draw the following conclusions and recommendations: There is a collective positive effect of students' strengths in the five selected mathematics topics on their performance in electrical and electronic engineering education, and this effect is mediated by their high-order thinking skills. Thus, learning to understand the concepts of Algebra, Functions, Trigonometry and Complex Numbers, Calculus and Differential Equations, and Probability will enhance electrical and electronic engineering students' academic achievement. Furthermore, students with higher-order thinking skills would do better than their colleagues with lower-order thinking skills. That is, there is a partial mediation in the positive effect of students' strength in mathematics on achievement in electrical and electronic engineering education by their higher-order thinking skills. Algebra is found to be the most influential mathematics area in the Ghanaian HND electrical and electronic engineering curriculum, and EEE222 (Control Systems) is the most affected engineering course.

To thrive in developing HOTS in mathematics for learning electrical and electronic engineering subjects, there should be a high level of understanding of the concepts of Algebra, Functions, Trigonometry and Complex Numbers, Calculus and Differential Equations, and Probability, especially in Algebra. To improve HOTS, students should do continuous revision and problem-solving among these topics of mathematics from textbooks used in mathematics learning in primary, secondary, and tertiary schools, with much attention to Algebra. Teachers should engage students in appropriate methods of teaching and learning mathematics concepts to promote students' critical and creative thinking. Literature recommends the RME approach, and we therefore recommend that it be intensified in the teaching of algebra, functions, trigonometry and complex numbers, calculus and differential equations, and probability. Mathematics is often viewed as an abstract subject with little relevance to the real world. The curriculum planners or developers in Ghana should therefore emphasize the practical applications of engineering mathematics in everyday life and provide opportunities for not only tertiary students but also pre-tertiary students to use their mathematical knowledge to solve real-world problems. Students should be trained with Pólya's framework of problem solving to increase HOTS and consequently achieve good results in their electrical and electronic engineering education.

The positive effect of mathematics strength on students' achievements in their education implies that students who are weak in Mathematics below a certain threshold may not be able to progress to the final year or successfully graduate with the HND in electrical and electronic engineering, and therefore we recommend academic intervention in the form of mathematics support for them.

Only five important mathematics indicators were considered for the study, and these, together with their higher-order thinking indicators, explained only 57% of the variation in students' achievements in electrical and electronic engineering education. We therefore recommend that more areas of engineering mathematics and other factors, such as students' pre-university mathematics background and attitude towards program of study, which may explain the unexplained variance of students' achievement, be investigated by future research.

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INSTITUTIONAL REVIEW BOARD STATEMENT

The Ethical Committee of the Universitas Pendidikan Indonesia, Indonesia on 9 January 2023 (Ref. No. 0066/UN40.SPs.41/2023) and the Ho Technical University, Ghana on 12 January 2023 (Ref. No. HTU/DRI/VOL. I/009) has granted approval for this study.

TRANSPARENCY

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Conceptualization, data gathering, methodology, writing original draft, formal analysis, and writing-review and editing revised version, T.O.; methodology, validation and supervision, B.M.; validation and formal analysis, and supervision, D.R.; data gathering, methodology, editing, G.O.; data gathering, editing, A.C.M.; conceptualization, methodology, formal analysis, K.A. All authors have read and agreed to the published version of the manuscript.

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