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Research Article

The effect of using photomath on pre-service teachers' algebra achievement: The mediating role of conceptual understanding

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This study explored the impact of Photomath on the mathematics achievement of pre-service teachers in algebra, with a focus on the mediating roles of conceptual understanding and interest. A total of 257 undergraduate Education students from Wiawso College of Education in Ghana were selected through stratified and simple random sampling. Using a quantitative research approach, data were collected via structured questionnaires and analyzed with AMOS software to examine the hypothesized relationships. The results revealed that Photomath usage significantly and positively influenced pre-service teachers' achievement in algebra. Furthermore, the direct effect of Photomath on algebra achievement was also found to be positive and statistically significant. In terms of conceptual understanding, Photomath had a significant and positive impact, enhancing students' comprehension of algebraic concepts. However, while Photomath showed a positive effect on students' interest, this relationship was not statistically significant. Notably, conceptual understanding was found to partially mediate the relationship between Photomath usage and mathematics achievement. These findings suggest that educators and institutions should consider integrating Photomath into algebra instruction to support student learning and achievement.

Keywords: Photomath, mathematics achievement, conceptual understanding, pre-service teachers

1. Introduction

In recent years, the use of Information and Communication Technology (ICT) within the educational sector has attracted considerable interest, particularly in the field of mathematics instruction. With the rapid advancement of digital technologies, educators are increasingly leveraging various technological tools to enhance the teaching and learning experience. The rise of digital technology has significantly transformed many sectors, including education. As the focus on STEM (Science, Technology, Engineering, and Mathematics) disciplines grows, there is an increasing need to explore innovative tools that can facilitate learning, especially in complex subjects like mathematics. Among these tools is Photomath, a mobile application that utilizes augmented reality to solve mathematical equations and provides detailed, step-by-step solutions. This study examines the impact of Photomath on the algebraic performance of pre-service teachers, with particular attention to the potential mediating roles of conceptual understanding and interest.

Photomath, a free mobile application developed by Microblink, allows users to solve mathematical problems by scanning them with a smartphone camera. The app includes features such as step-by-step solutions, interactive graphs, and support for a wide range of mathematical topics, from basic arithmetic to advanced calculus. Its popularity among students can be attributed to its user-friendly design and the immediate feedback it offers. According to Sloan-Lynch et al. (2022), Photomath has been downloaded more than 100 million times, reflecting its widespread use in educational contexts.

Despite its popularity, the educational value of Photomath remains a topic of debate. Some educators express concerns that reliance on such apps may undermine students' problem-solving abilities and conceptual understanding. Conversely, others argue that Photomath can be a valuable supplementary tool when integrated into a structured educational framework. Research by Llenada-Santos (2022) suggests that, when used alongside traditional methods, Photomath can reinforce learning rather than replace critical problem-solving activities. Moreover, Photomath demonstrates potential for personalized learning, allowing students to progress at their own pace. A study by Mitchell and Wilson (2021) found that students who used Photomath in conjunction with conventional instruction experienced improvements in mathematical performance, particularly in procedural fluency and algebraic skills. This suggests that, when used strategically, Photomath can enhance learning outcomes in algebra, a subject that many students find challenging.

Understanding mathematical concepts is essential for effective teaching and learning, as it involves more than performing operations; it requires a grasp of the underlying principles. This depth of understanding is particularly critical for pre-service teachers, who must be able to communicate mathematical ideas clearly and accurately to their future students. Engelbrecht et al. (2005) argue that conceptual understanding is the foundation for procedural fluency, playing a crucial role in solving new problems and linking various mathematical domains. For pre-service teachers, developing a strong conceptual base significantly enhances their teaching effectiveness.

Graham et al. (2012) emphasize the importance of incorporating technological tools into teacher education to improve conceptual understanding. Their findings revealed that pre-service teachers who used tools like Photomath were better able to visualize and comprehend complex algebraic concepts, which in turn enhanced their teaching capabilities. Furthermore, the use of technology to foster conceptual understanding aligns with constructivist learning theory, which posits that learners build knowledge through experience and reflection. Tools like Photomath support active learning, encouraging exploration of different solution strategies, immediate feedback, and opportunities for self-reflection. This perspective is supported by Herrelko (2017), who asserts that technological tools can deepen conceptual understanding when they promote exploration and critical thinking.

Algebra is a critical component of the mathematics curriculum and serves as a foundation for more advanced mathematical topics. However, it is a subject that many learners, including those training to become teachers, find difficult. Mastery of algebra is particularly important for pre-service teachers, as it forms a core part of the content they are expected to teach. In recent years, numerous studies have investigated the role of technological tools in improving mathematics achievement, particularly in algebra. Research indicates that apps like Photomath can significantly enhance students' understanding of algebraic concepts and boost their problem-solving skills. For instance, a study by Pikri et al. (2023) found that students who used Photomath as a supplementary resource performed better in algebra assessments than those who did not. This improvement was attributed to the app's detailed explanations and interactive features, which helped students better understand complex algebraic ideas.

The impact of Photomath on mathematical achievement is often mediated by factors such as conceptual understanding. As De Asis and Ucang (2022) noted, students with a strong foundation in algebraic concepts are more likely to benefit from technological tools, as these tools help reinforce learning and encourage exploration. Similarly, students with a genuine interest in mathematics are more inclined to engage with tools like Photomath and use them effectively to enhance their learning experiences. For pre-service teachers, improved proficiency in algebra through tools like Photomath contributes to their overall mathematical competence and confidence, which in turn positively influences their future teaching practices and their ability to engage and motivate students.

The integration of technology into mathematics education offers significant potential to transform the learning experiences of pre-service teachers. This research aims to examine how Photomath usage influences algebraic performance, with a particular focus on the mediating role of conceptual understanding. By exploring these relationships, the study seeks to provide insights into the effectiveness of technological tools in enhancing mathematics education. The findings aim to inform the development of teacher education programs that incorporate technology to improve educational outcomes.

2. Current Study

Algebra is a mandatory course for all college students training to become teachers. In Ghanaian colleges of education—affiliated with various public universities—this course is offered under different titles. As a result, there has been a notable increase in the teaching of algebra across these institutions. However, despite numerous studies aimed at improving outcomes, the academic performance of pre-service teachers in algebra has consistently fallen below expectations (Llinares & Quevedo, 2021; Morales & Parra, 2022). This persistent underperformance is a significant concern for educational stakeholders, as it directly affects students' success in mathematics (Sibgatullin et al., 2022).

In Ghana, a report by the Chief Examiner from the Institute of Education at the University of Cape Coast, cited by Essuman et al. (2024), revealed alarmingly low performance in college algebra courses during the first semester of the 2018/2019 academic year. The report indicated that the mean scores for Algebra I and Algebra II were 12.46% and 12.45%, respectively, with considerable variability among students. Given these challenges, the present study seeks to examine pre-service mathematics teachers' proficiency in selected algebra topics, including basic algebraic operations, equations and inequalities, and exponents and radicals, which are part of Ghana's basic school curriculum.

Research has suggested that the use of Photomath in educational settings can improve mathematics achievement among pre-service teachers (Hamadneh et al., 2015). Likewise, Zain et al. (2023) found a significant positive impact of Photomath on general mathematics performance. However, while existing studies have primarily focused on general mathematics, there is limited research specifically addressing the effects of Photomath on algebra performance. Therefore, this study investigates the impact of Photomath utilization on the algebraic achievement of pre-service teachers, with particular attention to the mediating roles of conceptual understanding and interest.

To contribute to the growing body of knowledge, this study explores whether pre-service teachers' conceptual understanding mediates the relationship between their use of Photomath and their achievement in algebra. The study is guided by the following research questions:

RQ 1) What is the effect of pre-service teachers' Photomath utilization on their conceptual understanding in algebra?

RQ 2) What is the effect of pre-service teachers' Photomath utilization on their interest in algebra?

RQ 3) What is the mediating effect of pre-service teachers' conceptual understanding on the relationship between Photomath utilization and their mathematics achievement in algebra?

RQ 4) What is the mediating effect of pre-service teachers' interest on the relationship between Photomath utilization and their mathematics achievement in algebra?

3. Literature Review

3.1. Theoretical Framework of the Study

Constructivism is a well-established learning theory that emphasizes the construction of knowledge through mental processes and interaction with the environment (Mohammed & Kinyo, 2020). In the context of mathematics education, research suggests that effective learning occurs when students actively construct their own understanding of mathematical concepts (Lestari & Surya, 2017). According to constructivist learning theory, knowledge is developed through the interplay between learners and environmental influences. New information is more effectively understood, absorbed, and retained when it aligns with the learner's existing cognitive framework (Salimon et al., 2021).

A core element of constructivism is the development of cognitive tools that integrate learners' prior experiences with the context in which learning takes place. For learning to be effective, it must involve three essential components: engagement in practice, acquisition of knowledge, and consideration of the cultural context (Kahn & Agnew, 2017). Constructivism asserts that meaning is actively constructed by the learner, rather than passively received. As such, knowledge is interpreted in multiple ways based on individual experience—there is no single, definitive understanding that can be derived from every learning interaction.

Learners develop their perspectives not by memorizing external information but through personal experience and interaction with available resources. While both constructivist and cognitivist theories view students as active participants in the learning process, constructivists emphasize that learners go beyond merely processing information—they interpret, evaluate, and build upon it (Ardiansyah & Ujihanti, 2017).

In constructivist classrooms, learning objectives are not rigidly predetermined; rather, learners generate meaning through exploration and application. This approach encourages educators to move from simply delivering content to engaging students in meaningful, real-world problem-solving. Constructivism views students as dynamic processors of information who extract relevant knowledge through active engagement. As Suhendi (2018) notes, constructivists believe that the conditions under which individuals learn profoundly influence their behavior, underscoring the need for transformative instructional practices.

In this regard, the constructivist framework is especially relevant to this study, as it offers insights into how instructional strategies can be adapted to improve conceptual understanding in mathematics. The type of learning that takes place in the classroom, along with the teacher's ability to effectively facilitate instruction, plays a critical role in shaping students' conceptual grasp of mathematical ideas.

3.2. Conceptual Review

The conceptual framework serves as the foundation of a study, aligning its goals with appropriate methodologies and ensuring that the research addresses its core questions in a coherent and logical manner. In this study, the mediating role of conceptual understanding in mathematics helps clarify the relationship between Photomath usage and pre-service teachers' achievement in algebra during the teaching and learning process.

As noted by Thurm and Barzel (2022), Photomath has become an important tool in mathematics education, enhancing pre-service teachers' understanding of mathematical concepts. However, its impact on mathematical achievement can vary based on the depth of the teacher's conceptual understanding. Cullen et al. (2020) suggest that incorporating Photomath into mathematics instruction can positively influence pre-service teachers' academic success, though this effect may be moderated by their performance in algebra, as highlighted by Hu et al. (2022). Johnson and Rodriguez (2021) also emphasize that mathematics achievement can be significantly enhanced when Photomath is effectively integrated into instruction. According to Arhin and Gideon (2020), both algebra achievement and the use of Photomath influence pre-service teachers' conceptual understanding, suggesting that this understanding may mediate the relationship between Photomath use and algebra performance.

Overall, the effectiveness of Photomath in mathematics instruction—and its influence on algebra achievement—is significantly shaped by the level of conceptual understanding among pre-service teachers. Therefore, conceptual understanding serves as a critical mediating variable, bridging the use of technological tools like Photomath and measurable academic outcomes in algebra.

3.3. Empirical Review

Empirical studies refer to original research reports and are essential for developing innovative concepts, refining study methodologies, and expanding the scope of academic inquiry. Every study must build on existing research, requiring scholars to have a strong understanding of the subject's background and prior findings. One such area of interest is the use of educational technologies like Photomath, a mobile application that enables students to solve mathematical problems by scanning them with their smartphone cameras. Owing to its widespread use and perceived effectiveness, numerous empirical studies have examined Photomath's impact on student engagement, learning outcomes, and overall educational value.

Research indicates that Photomath can significantly enhance students' understanding of mathematical concepts. For instance, Saundarajan et al. (2020) found that students who used Photomath demonstrated stronger problem-solving skills and higher accuracy in mathematical calculations compared to peers who did not use the app. The app's immediate feedback was identified as a key feature contributing to learning efficiency. Similarly, Alayont and Bourgonje (2020) reported that students using Photomath completed homework more quickly and accurately, suggesting that the app streamlines the learning process. In addition to cognitive gains, Photomath also appears to increase students' motivation and conceptual understanding. In a survey conducted by Johnson and Rodriguez (2021), many students indicated that using Photomath made math lessons more enjoyable and less stressful. An empirical study by Muñoz Lucas and Sanchez García (2018) revealed that students who used Photomath developed a stronger grasp of algebraic concepts compared to a control group. The app's step-by-step solution feature helped students visualize problem-solving processes, thereby deepening their conceptual understanding. Kim et al. (2019) further observed that frequent users of Photomath performed significantly better on standardized math tests, concluding that consistent use of the app for practice and exam preparation led to overall academic improvement. Johnson and Rodriguez (2021) also emphasized that Photomath supports differentiated learning, enabling students to progress at their own pace. The app's ability to offer personalized feedback and multiple solution strategies was particularly beneficial for students with diverse learning needs. In a survey conducted by Chen and Park (2023), educators and students reported that Photomath effectively enhanced classroom learning. They praised the app's immediate feedback and detailed explanations, which helped address specific learning gaps.

Photomath, developed by the software company Microblink, is a smartphone application that allows users to solve math problems by scanning them or entering them manually (Alrajeh, 2021). Beyond simply displaying the answer, the app provides step-by-step solutions, helping users understand the methods and reasoning behind the problems and thereby enhancing their overall mathematical proficiency. The importance of mathematics in fostering intellectual and personal development is profound. As noted by Al-Takhyneh (2018), mathematics is understood as a network of interconnected concepts, beliefs, and processes. Effective teaching requires building connections between key ideas to facilitate comprehension, particularly for pre-service teachers. The teaching and understanding of mathematics are essential for preparing learners to participate in the global knowledge economy, underscoring the subject's significance in modern education. For mathematics instruction to be effective, students must first understand the content and then be motivated and supported to achieve a deep and lasting understanding (Al Umairi, 2024; Ramirez, 2024).

3.4. Conceptual Framework

3.4.1. Photomath utilization [PU]

This variable refers to the frequency and effectiveness with which pre-service teachers utilize the Photomath app to solve algebraic problems. Photomath provides detailed, step-by-step solutions that assist learners in deconstructing and understanding complex algebraic equations. In the context of this study, Photomath utilization functions as the independent variable, with the potential to influence other key constructs such as conceptual understanding, interest, and ultimately, achievement in algebra. The underlying assumption is that more frequent or purposeful use of Photomath may positively impact these related variables, thereby enhancing the overall learning experience and academic performance in algebra.

3.4.2. Pre-service teachers' conceptual understanding [PTCU]

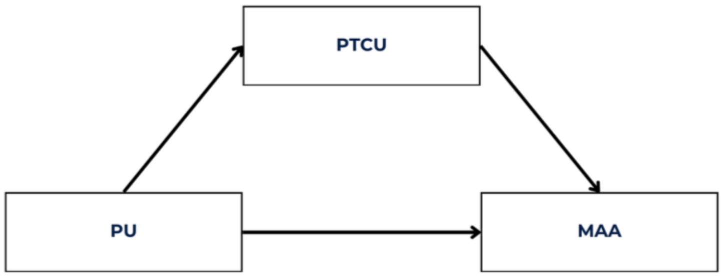
Conceptual understanding refers to the extent to which pre-service teachers comprehend the fundamental principles of algebra, moving beyond rote memorization of formulas and procedures. When used effectively, Photomath can support this understanding by providing step-by-step solutions that clarify underlying processes. A deeper conceptual grasp enables learners to apply algebraic concepts to novel and varied problem contexts with greater accuracy and flexibility. In this study, conceptual understanding is positioned as a mediating variable in the relationship between Photomath utilization and algebra achievement. That is, it is hypothesized that the app improves algebra performance indirectly by first enhancing students' understanding of algebraic concepts.

3.4.3. Mathematics achievement in algebra [MAA]

This dependent variable represents the algebraic performance outcomes of pre-service teachers following their use of Photomath. The primary objective of the study is to evaluate whether Photomath use contributes to improved mathematics achievement, and to what extent this relationship is mediated by conceptual understanding and interest. In essence, the impact of Photomath on achievement may be more pronounced indirectly—through its influence on understanding and engagement—than through its direct use alone.

Photomath utilization is hypothesized to have a direct effect on both conceptual understanding and interest. These two variables act as mediators, helping to explain how Photomath leads to improved performance in algebra. The greater a pre-service teacher's grasp of algebraic concepts and interest in the subject, the more likely they are to demonstrate enhanced academic achievement. Ultimately, this study aims to demonstrate that Photomath contributes not only by offering step-by-step solutions but also by deepening conceptual understanding and increasing motivation, both of which are critical for improved learning outcomes in algebra. Figure 1 summarizes the framework.

Figure 1
Conceptual Framework



4. Method

4.1. Research Approach

A quantitative research approach is particularly well-suited for examining the effects of Photomath usage on pre-service teachers' mathematics achievement in algebra, especially when considering mediating factors such as conceptual understanding and interest. This methodology enables the collection and analysis of numerical data related to key variables—such as achievement scores and levels of conceptual understanding—which are critical for assessing the impact of Photomath. Participants' responses can be gathered through structured instruments, such as 5-point Likert scales or similar rating formats, aligning with standard quantitative methods.

Such an approach facilitates the statistical examination of relationships between variables, allowing researchers to measure the extent to which the use of Photomath correlates with improvements (or declines) in mathematics performance. Consistent with most quantitative studies, this research decomposes the teaching and learning processes into measurable components—like test scores and self-assessed understanding—which are then converted into numerical values for analysis.

The study is also likely to adopt a deductive reasoning framework, in which hypotheses are developed from existing theories on the role of ICT tools in mathematics education. Data is then systematically collected to test these hypotheses, using controlled and objective instruments, such as structured questionnaires. This objectivity enhances the generalizability of the findings, especially if the sample is representative of the wider pre-service teacher population.

Overall, by using a quantitative approach, the study benefits from precise measurement, replicability, and statistical rigor, making it possible to establish evidence-based conclusions about the effectiveness of Photomath. Such findings can inform future recommendations for ICT integration in mathematics education.

4.2. Research Design

Research design refers to the overarching methodological framework employed to address the primary research question. It encompasses the full strategy for conducting a study, including data collection methods, participant selection, and procedural execution. The fundamental objective of a research design is to establish a structured plan for gathering empirical evidence that directly informs the research questions (Mangobi et al., 2023). In this study, a descriptive survey design was selected. This design entails collecting data from a sample at a single point in time using a questionnaire to capture individuals' opinions, perceptions, behaviors, or characteristics. As noted by Al-Takhyneh (2018), descriptive surveys rely on questionnaires to obtain quantifiable data, which can then be analyzed statistically to identify patterns, trends, and relationships that help in testing research hypotheses. The descriptive survey design was deemed appropriate for this research due to its effectiveness in collecting data from a large number of participants in a relatively short timeframe. It is particularly suited to exploring the mediating role of pre-service teachers' conceptual understanding in their mathematics achievement in algebra, especially in the context of Photomath usage. Descriptive surveys are commonly employed in educational research to address questions such as "What is happening?", "How is it happening?", and "Why is it happening?" They offer a practical approach to collecting and interpreting accurate and generalizable information, making them an ideal choice for investigating complex constructs within teaching and learning environments.

4.3. Participants

Participants were selected using a combination of stratified and simple random sampling. The population was first divided into subgroups (strata) based on relevant characteristics, and samples were then randomly drawn from each subgroup in proportion to their size. This method ensured fair representation of all subgroups and enhanced the accuracy of the results. Within each stratum, simple random sampling was used to ensure each individual had an equal chance of being selected.

A total of 257 students were selected using a simple random sampling technique to ensure representativeness and minimize bias. Participants were randomly chosen by drawing "YES" or "NO" papers, with only "YES" respondents included. The sample distribution was 35% from Level 100, 37% from Level 200 (the largest group), and 28% from Level 300. The sampling process followed established guidelines for reliability and accuracy in educational research. Characteristics of the participants are summarized in Table 1.

Table 1
Background Information on Pre – Service Teachers

Demographics	*Frequency*	*Percentage %*
Level 100	90	35.0
Level 200	95	37.0
Level 300	72	28.0
Totals	257	100.0

4.4. Data Collection

The study used closed-ended, structured questionnaires adapted from existing instruments to collect data efficiently and anonymously from a large sample. Based on Cohen and Manion (2011), questionnaires are effective self-report tools, and the version used was informed by Hooper et al. (2016). The survey focused on variables such as Photomath usage, conceptual understanding, interest, and Algebra achievement. It comprised two sections: one for biographical data and another addressing research questions through 40 closed-ended items. A 5-point Likert scale was used to measure participants' levels of agreement, allowing for effective assessment of attitudes and opinions.

4.5. Data Analysis

The study adopted a descriptive survey approach and analyzed the quantitative data using SPSS and AMOS (version 23). Exploratory Factor Analysis (EFA) was conducted in SPSS to explore the connections between observed and latent variables and to refine the structure by eliminating items with poor loadings. Structural Equation Modeling (SEM) and path analysis were performed in AMOS to examine the relationships among independent and dependent variables, thereby validating theoretical assumptions and providing a clearer understanding of the underlying model.

5. Results and Discussion

5.1. Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) was conducted using SPSS version 23 to examine the underlying structure of the data. The primary objective was to identify the relationships among factors and ensure that each observed variable appropriately loaded onto its corresponding latent variable. This analysis facilitated the refinement of the measurement model by identifying and potentially eliminating items that did not align well with the intended constructs. The final results of the EFA, which display the observed variables grouped under their respective latent variables, are summarized in Table 3.

Table 2

Exploratory Factor Analysis

Rotated Component Matrix

Measurement Items	Component 1	2	3	4
PTCU1				.734
PTCU2				.795
PTCU3				.596
PTCU4				.796
PTCU5				.764
MAA3		.808		
MAA4		.782		
MAA5		.818		
MAA6		.840		
MAA7		.683		
PU2			.862	
PU3			.846	
PU4			.867	
PU5			.871	

5.2. Confirmatory Factor Analysis

Confirmatory Factor Analysis (CFA) was conducted using AMOS software (Version 23). CFA is recognized for its versatility and is widely applied across various fields due to its ability to estimate multiple statistical parameters (Arthur, 2022; Pomegbe et al., 2019). In this study, CFA was used to validate the factor structure identified through Exploratory Factor Analysis (EFA). Only the observed variables that emerged from the rotated components in the EFA were included in the CFA. The analysis retained factors with loadings above 0.4, while variables with factor loadings below 0.5 were excluded from the model. The detailed results of the CFA are presented in Table 5.

Table 3
Confirmatory Factor Analysis

Model Fits: CMIN = 371.031; DF = 142; CMIN/DF = 2.613; TLI = .926; CFI = .938; RMR = .0524; RMSEA = 0.53;	Estimate
PU: CA = .916	
PU2: Photomath improve pre – service teachers' engagement and motivation in mathematics classes.	.809
PU3: Integrating Photomath in teaching mathematics facilitates pre – service teachers' centered learning.	.861
PU4: The use of Photomath in teaching mathematics promotes creativity and innovative.	.881
PU5: Photomath support the exploration and discovery mathematical concepts.	.891
PTCU: CA = .885	
PTCU1: I have difficulties understanding anything related to mathematics.	.703
PTCU2: I give up easily when working on mathematics.	.844
PTCU3: Mathematics concepts are difficult to understand.	.645
PTCU4: Mathematics is complex in nature.	.887
PTCU5: Mathematics is one of my strengths.	.825
MAA: CA = .903	
MAA3: My math teacher says I do well in linear algebra.	.837
MAA4: I might think about taking further courses in linear algebra.	.853
MAA5: One of my weaknesses in math is linear algebra.	.810
MAA6: In mathematics, I get things quite rapidly when it comes to linear algebra.	.789
MAA7: I struggle more than many of my classmates with linear algebra in mathematics.	.702

Based on the analysis presented in Table 5, Marsh et al. (2020) emphasize the importance of several key model fit indices in Confirmatory Factor Analysis (CFA). Specifically, they recommend that the CMIN/DF ratio (chi-square divided by degrees of freedom) should ideally be less than 3 to indicate a good model fit. Furthermore, the Root Mean Square Residual (RMR) and the Root Mean Square Error of Approximation (RMSEA) should each be no greater than 0.08. Acceptable thresholds for the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI) are values of 0.90 or above.

According to Kebritchi et al. (2010), the CMIN statistic assesses the discrepancy between the hypothesized model and the observed data, while RMR and RMSEA evaluate model fit by estimating the degree of residual error. The TLI and CFI, both based on normal theory for continuous data, reflect the comparative fit of the model relative to a null or baseline model.

The structural representation of the Confirmatory Factor Analysis is shown in Figure 2.

Table 4
Discriminant Validity

Variables	*CR*	*AVE*	*PU*	*PTCU*	*MAA*
PU	.920	.742	.861		
PTCU	.889	.618	.463	.786	
MAA	.898	.640	.387	.695	.800

To further examine the study and confirm convergence validity, both the Average Variance Extracted [AVE] and Composite Reliability [CR] were calculated. The results revealed that AVE was at least 0.618 and CR was 0.889, meeting the standards set by Dogbe et al. (2019). Discriminant validity was evaluated based on the methods suggesting that discriminant validity is confirmed when the square root of AVE exceeds the correlation coefficient. The correlation coefficients were obtained from the CFA results using covariance. Table 3 illustrates the comparison between the square root of AVE and the corresponding correlations of the latent variables.

5.3. Path Summary

Table 7 assesses the direct and indirect impacts of the study's hypotheses through path analysis. This method allows for the breakdown of the correlations between the independent and dependent variables, aligning with theories established by previous researchers. The study utilized Factor Analysis and multiple regression analysis, applying Structural Equation Modeling via Amos.

Table 5
Path Summary

Direct Effect	*Estimate*	*S.E.*	*C.R.*	*p-value*
PTCU←PU	.499	.077	6.482	< .01
PTIN←PU	.320	.080	4.023	< .01
MAA←PTCU	.843	.094	8.968	<.01
Indirect Effect	*Estimate*	*LBC*	*UBC*	*p-value*
PU → PTCU → MAA	0.047	0.016	0.130	.227

The first research problem focused on examining the effect of Photomath utilization on pre-service teachers' conceptual understanding in algebra. An answer to this problem was sought. The findings revealed that the use of Photomath had a statistically significant and positive impact on pre-service teachers' understanding of algebraic concepts ($p < .05$; $\beta = .499$; C.R = 6.482).

The second research problem aimed to explore the effect of Photomath utilization on pre-service teachers' mathematics achievement in algebra. An answer to this problem was sought. As presented in the path summary in Table 7, the results indicated that the use of Photomath significantly and positively enhanced pre-service teachers' mathematics achievement in algebra ($p < .05$; $\beta = .843$; C.R = 8.968).

The third research problem addressed the mediating role of pre-service teachers' conceptual understanding in the relationship between Photomath utilization and their mathematics achievement in algebra. An answer to this problem was sought. The mediating effect was analyzed using Structural Equation Modeling (SEM) in Amos (version 23), employing a bootstrap method with 5,000 samples. The interpretation of the bootstrap results relied on the confidence interval: for the indirect effect to be considered significant, both the lower and upper bounds had to lie on the same side of zero. In this analysis, the lower bound was 0.016 and the upper bound was 0.130. Since both values were positive, the mediation effect was found to be statistically significant. These findings suggest that pre-service teachers' conceptual understanding partially mediated the relationship between Photomath usage and their achievement in algebra. Specifically, 4.7% of the effect of Photomath usage on algebra achievement was mediated through conceptual understanding.

6. Discussion and Conclusion

This study examined the impact of using Photomath on pre-service teachers' understanding and performance in algebra. The findings revealed a statistically significant positive relationship, indicating that increased use of Photomath enhances pre-service teachers' conceptual grasp of algebra. This outcome is consistent with previous research by Lee and Tran (2020), who also emphasized the effectiveness of Photomath in improving conceptual understanding among pre-service teachers. Furthermore, Asare et al. (2024) highlighted the strong connection between students' conceptual understanding of mathematics and their academic performance. Their large-scale study, involving 158,161 participants, confirmed that Photomath usage significantly contributes to the development of conceptual comprehension.

In addition to conceptual understanding, the analysis demonstrated that Photomath usage positively influences pre-service teachers' algebra performance. As shown in Table 6, this relationship was statistically significant ($p < .05$), suggesting that frequent use of Photomath is associated with improved achievement in algebra. These findings align with those of Zain et al. (2023), who also reported a positive relationship between Photomath use and algebra achievement. Similarly, Smith and Doe (2020) found a modest to moderate correlation between the use of Photomath and algebra performance, along with observed increases in student motivation, underscoring the multifaceted benefits of integrating technology into mathematics education.

The mediation analysis further explored the role of conceptual understanding in the relationship between Photomath utilization and algebra achievement. For an indirect effect to be considered statistically significant, the lower and upper bounds of the confidence interval must both be either entirely positive or entirely negative, excluding zero. In this study, the lower bound was 0.016 and the upper bound was 0.130, indicating a significant mediation effect. Specifically, the results showed that conceptual understanding accounted for approximately 4.7% of the total effect of Photomath use on algebra achievement. This implies that pre-service teachers' conceptual understanding positively mediates the relationship between their use of Photomath and their performance in algebra, as further confirmed by the results presented in Table 7.

These findings are supported by previous literature. For instance, Boadu (2024) demonstrated that algebra achievement is a significant predictor of Photomath utilization in the context of in-service instructors' conceptual understanding. Likewise, Nurhayati et al. (2021), in a study involving 300 students from Sakafia Islamic Senior High School and Kumasi Academy Senior High School, found that Photomath usage contributed to improved performance in algebra.

In summary, the study concludes that Photomath has a statistically significant and positive effect on both the conceptual understanding and algebra achievement of pre-service teachers. It also plays a mediating role by strengthening the link between understanding and performance. These findings underscore the potential of Photomath as an effective educational technology tool to support the teaching and learning of algebra in teacher education programs.

7. Educational Implications

The findings of this study highlight the value of incorporating Photomath into algebra instruction and suggest several practical implications for educational practice. Educators and institutions are encouraged to integrate Photomath into their teaching strategies to enhance students' conceptual understanding of algebra. Teachers can also promote the use of Photomath for homework and practice exercises, allowing students to reinforce their learning outside the classroom. For curriculum developers, the results suggest embedding Photomath as a supplementary tool within algebra courses, ensuring its alignment with specific learning objectives. This could include incorporating Photomath into lesson plans and using it as part of interactive classroom activities. Furthermore, professional development agencies should consider organizing workshops and training sessions focused on effective strategies for using Photomath in algebra instruction. Developing practical guides and instructional resources that demonstrate how Photomath can be integrated into diverse teaching contexts would also support educators in adopting this tool meaningfully.

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

Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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

Ethics statement: All participants provided informed consent prior to their involvement in the study. They were informed about the study's purpose, procedures, and their right to withdraw at any time without consequence.

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