

Generative AI Usage and Digital Competence as Predictors of Mathematics Teaching Effectiveness among Pre-Service Teachers

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ABSTRACT

The growing use of Generative Artificial Intelligence (GenAI) in education presents new opportunities for improving mathematics teaching, but its effectiveness may depend on teachers' ability to use digital technologies critically and appropriately. This study examined Generative AI Usage and Digital Competence as predictors of Mathematics Teaching Effectiveness among pre-service teachers who had completed teaching practice. A quantitative cross-sectional survey design was employed, involving 217 Level 400 pre-service teachers from Colleges of Education in the Hohoe Municipality. Data were collected using a five-point Likert-scale structured questionnaire and analysed using Structural Equation Modelling (SEM) in SPSS AMOS Version 23. The measurement model demonstrated good fit, while all constructs showed acceptable reliability and validity. The findings revealed that Generative AI Usage significantly and positively predicted Mathematics Teaching Effectiveness ($\beta = 0.181$, $p = .010$). Digital Competence also significantly and positively predicted Mathematics Teaching Effectiveness ($\beta = 0.461$, $p < .001$), with a stronger predictive effect than GenAI Usage. The study concludes that while GenAI can support effective mathematics teaching, digital competence is particularly important for enabling pre-service teachers to evaluate, adapt, and integrate digital resources meaningfully into instruction. Teacher education institutions should therefore promote digital competence development alongside responsible and pedagogically informed use of GenAI in mathematics teacher preparation.

1. Introduction

The rapid emergence of Generative Artificial Intelligence (GenAI) has changed the landscape of the field of education by virtue of the capabilities that GenAI teachers may have to generate lesson plans, math examples, educational materials, assessment tasks, and even different types of explanations (Ceallaigh & Murphy, 2026). These capabilities may be used in the realm of math education to improve lesson preparation and engagement. But, the availability of GenAI and its uses cannot guarantee good teaching (Hsu et al., 2024). The outputs of the artificial intelligence in mathematics can be incorrect in terms of mathematical concepts, pedagogy, and need modifications according to the

requirements of the learners (Lee & Song, 2024). Thus, the effectiveness of GenAI in mathematics teaching lies heavily in teachers' evaluation and modification of GenAI outputs.

The question of digital literacy is associated not only with the skills associated with the usage of technologies but also with the selection, evaluation, creation, and integration of digital resources that are employed for educational purposes (Soliman, 2026). As for math teachers, the issue of digital literacy acquires special importance since the effective employment of technologies implies the availability of appropriate mathematical content and differentiation (Mariscal et al., 2023). Although there has been increasing research in the area of GenAI and teacher training, no empirical proof has been found that can prove that GenAI usage and digital competence really predict mathematics teaching effectiveness, especially for those pre-service teachers who have done teaching practice. The significance of this gap comes from the fact that teaching practice gives a chance for the teacher candidate to use his/her technological know-how into teaching.

1.1 Problem Statement

GenAI has become more and more prevalent in mathematics education because it helps educators in preparing lessons, preparing instructional materials, creating mathematical tasks, and supporting the learning of students (Walkington et al., 2026). Pre-service teachers may make use of the content created using AI technology without critical reflection on the mathematical accuracy, pedagogical appropriateness, or relevance to the needs and contexts of their learners (Kul et al., 2026). Therefore, the proper utilization of GenAI in mathematics teaching requires not just the use of technology but also critical thinking on how to analyze, adapt, and integrate the output generated by these technologies into the practice (Valle et al., 2026). However, general digital literacy has become increasingly essential for teachers to reflect critically on digital technologies used in education and incorporate them into instructional processes (Bueno-Baquero et al., 2026). Even though the number of studies related to the field of GenAI and teacher education continues to grow, there is still no empirical evidence on the link between the extent of usage of GenAI and digital competency and mathematics teaching effectiveness of pre-service teachers. Therefore, there is an important empirical gap which shows that the relationships between higher usage of GenAI and digital competence and mathematics teaching effectiveness are yet to be determined.

1.2 Purpose of the Study

Research Objective is to determine the effect of Generative AI usage and digital competency on the teaching effectiveness of Mathematics for pre-service teachers.

Specifically, the study aims to:

1. To determine whether there is a connection between Generative AI Use and Teaching Effectiveness in Mathematics;
2. To investigate whether Digital Competence is a predictor of Mathematics Teaching Effectiveness.

1.3 Research Hypotheses

These hypotheses will be tested in the study:

1. **H₁:** Usage of Generative AI significantly predicts the effectiveness of mathematics teaching among pre-service teachers.
2. **H₂:** Mathematics Teaching Effectiveness is significantly predicted by Digital Competence among pre-service teachers.

Conceptual framework

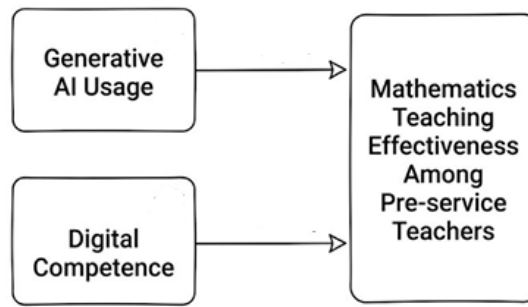


Figure 1: conceptual framework

1.4 Theoretical Foundation

1.4.1 Technological Pedagogical Content Knowledge (TPACK)

The TPACK framework suggested by Mishra and Koehler is undoubtedly going to be very useful in this research. According to TPACK, for technology integration, there should be interaction between knowledge of technology, pedagogy and content and not only of technology knowledge (Hidayat et al., 2024). Such a framework is very suitable in this case since using technology in mathematics classes requires more than knowledge of the tool itself (Yue et al., 2024). The prospective mathematics teacher should know which mathematical content should be taught, how it should be taught and how the technology should be applied.

Integration of GenAI into this framework is logical. A pre-service teacher may instruct ChatGPT to generate problems on quadratic equations, but for effective teaching, the teacher should be able to judge whether the generated problems are mathematically correct, appropriate according to the curriculum, learner-friendly and useful pedagogically (Trocado et al., 2025).

2. Literature Review

2.1 Generative AI Usage in Teacher Education

Generative AI is any artificial intelligence that is capable of generating various content including texts, images, explanations, questions, and other content based on input prompts by the users (Storey et al., 2025). From an educational perspective, the fast growth of various programs, such as ChatGPT, has resulted in an increased interest in applying such tools for teaching, learning, and assessment (Cerero et al., 2025). For the pre-service teachers, GenAI can be a planning assistant, resources generator, ideas generator, and feedback system (Blonder et al., 2024). Recent literature suggests that pre-service teachers employ GenAI in the process of lesson planning to generate content for instructions, followed by modification of the lesson plan (Celik et al., 2025). The use of ChatGPT has been examined with respect to its ability to serve as an instructional assistant for preservice secondary mathematics teachers (Gurl et al., 2024). Additionally, research has been conducted on the feasibility of using ChatGPT in the construction of 5E lesson plans for preservice mathematics teachers, whereby it was found that GenAI is both useful and restrictive in education (Yanar & Ergene, 2025).

GenAI has the potential to improve mathematics teaching through multiple pathways. It can cut down the amount of time needed for preparing teaching materials (Liu et al., 2026). It can create a multitude of mathematical examples and problems, it can help teachers design differentiating activities, it can give alternative explanations of complex mathematical concepts and it can help in creating formative assessment questions and feedback (Liu et al., 2026; Redmond-Sanogo et al., 2025). One study examined the creation of motivationally supportive mathematics lessons by teachers employing ChatGPT and found that AI supported lessons were associated with more messages of utility-value, non-canonical examples, and specific feedback, and students perceived less boredom (Rutherford et al., 2025). However, there are also several drawbacks to GenAI usage. In one research paper, where researchers worked with pre-service mathematics teachers, the difficulties in evaluating the mathematical validity of AI-generated messages were noted. Hence, the relationship between GenAI usage and efficient teaching should not be considered as technological determinism. The main concept in the current paper is that GenAI usage is good since it expands

teachers' teaching resources, although the educational significance of GenAI usage will be determined by teachers' evaluation of the resources (Gasaymeh, 2026).

2.2 Digital Competence and Mathematics Teaching

Digital competence is defined as the skill that the teacher uses digital tools in his professional practice (Asagar, 2025). The DigCompEdu framework presents six domains of educator competence, namely professional engagement, digital resources, teaching and learning, assessment, empowering learners and facilitation of learner digital competence (Feng & Xue, 2023). This definition of the concept is extremely useful for mathematics education as it touches upon virtually every aspect of teaching mathematics (Geraniou et al., 2024). Digitally competent mathematics educators are capable of searching for instructional materials, assessing their credibility, using digital technologies appropriately, designing digital activities, assessing students with technology, and giving digitally mediated feedback to students (Amhag et al., 2019).

The systematic analysis of the quantitative studies concerning the issue of teacher digital competence revealed the following features of teachers which were mostly explored in scientific works: the ability of teachers to plan digital lessons, using digital technologies for conducting lessons, implementing digital tasks at lessons, as well as developing digital skills of the students.

Therefore, digital competence cannot be treated as an additional feature connected with technologies only. Digital competence is one of the important aspects of teacher professionalism in the current environment (Asagar, 2025). In terms of pre-service mathematics teachers, the reasoning is even more compelling. Transition of pre-service teachers from institutions of teacher education to the classroom setting implies the need to convert theoretical knowledge into practical pedagogical decisions. In this regard, pre-service teachers with high competence on technology would be well suited to find out appropriate technological tools for representing mathematical concepts and creating digital activities through the use of these technological tools that would help students with varying abilities (Marais, 2023). Research findings coming from Ghana indicate that pre-service teachers are becoming more interested in integrating technology in the teaching of mathematics. There have been research studies conducted on the attitudes of pre-service teachers towards integration of technology in mathematics lessons and even specific topics like geometry and algebra (Essuman & Wilmot, 2024). Nevertheless, having positive attitudes is not enough. What is really essential for teaching is the ability to convert technological knowledge into practice.

2.3 Generative AI Usage, Digital Competence and Mathematics Teaching Effectiveness

The central thesis supporting this study is that there is a clear distinction between the concepts of GenAI use and digital competence. GenAI use is a term that refers to actions taken by preservice teachers using generative AI, while digital competence refers to their ability to use digital technology efficiently and effectively.

A pre-service teacher can often use ChatGPT while having low levels of digital competence. In other words, a teacher may accept explanations of mathematical phenomena produced by AI software without checking the correctness of such explanations. On the contrary, one pre-service teacher can have high levels of digital competence but rarely use AI software due to organizational reasons, preferences, or lack of opportunities (Aydoğdu & GiRit-Yildiz, 2026). These examples illustrate the necessity to consider the two constructs separately as variables of a conceptual model. Research in the recent years confirms such a distinction. In the studies of pre-service teachers, GenAI is shown to promote lesson planning and professional development, however, the process requires human mediation (Wu et al., 2025). The same is valid for AI literacy when researchers call teacher education programs to consider not only technical but also practical and ethical aspects of AI (Sperling et al., 2024). Thus, the present conceptual model assumes the existence of independent direct connections between the two variables and mathematics teaching effectiveness.

3. Method

3.1 Research Paradigm

This research was conducted using the positivist research paradigm that involves the measurement of objectivity and empirical observation of the relationship among variables (Junjie & Yingxin, 2022).

3.2 Research Approach and Design

Application of the quantitative approach to research became inevitable because of the nature of the study which requires collection and analysis of numbers in the process of developing a relationship between variables (Ghanad, 2023). This is evidenced in the cross-sectional survey design aimed at predicting the relationship between Generative AI utilization, digital competence, and mathematics teaching.

3.3 Population

The sample involved Level 400 trainee teachers from the Colleges of Education in the Hohoe Municipality who have gone through teaching practice.

3.4 Sampling and Sample Size

The sample size was calculated using the sample size determination table by Krejcie & Morgan (1970). Based on a population of 500 individuals, a sample size of 217 pre-service teachers was deemed appropriate at 95% confidence level with a margin of error of 5% (Uakarn et al., 2021). Stratified random sampling technique was used to select the 217 respondents who took part in the study.

3.5 Instrument

The data were collected through a structured questionnaire that had three main constructs, namely, Generative AI Use (GAIU), Digital Competence (DC), and Mathematics Teaching Effectiveness (MTE). Measurement of the constructs was performed using five close-ended questions. A five-point Likert Scale was used in recording answers with 1 being 'Strongly Disagree' and 5 being 'Strongly Agree.'

4. Data Analysis

Using SPSS AMOS.V.23, Structural Equation Model (SEM) was employed by the researcher to test the collected data. The variables used in this research are Generative AI Usage (GAIU), Digital Competence (DC), and Mathematics Teaching Effectiveness (MTE). Exploratory Factor Analysis (EFA) was carried out on the research items in order to identify how the items are grouped with respect to each specific factor. The theoretical model was then examined using a structural equation model (SEM) that demonstrated path analysis and CFA with 95% confidence interval and 0.05 alpha level.

Table1. Demographic Data

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	105	48.4
	Female	112	51.6
Age (years)	18–22	123	56.7
	23–27	82	37.8
	28 and above	12	5.5
Academic Level	Level 400	217	100
Programme of Specialisation	JHS Education	97	44.7
	Primary Education	70	32.3
	Early Grade Education	50	23
Total	Respondents	217	100

Source: field data, 2026

The demographic features of the 217 participants in this study are depicted in Table 1 above. Females were more than males (51.6% compared to 48.4%). Most of the subjects were aged 18-22 years (56.7%), then came the rest who were aged 23-27 years (37.8%), and those who were above 28 years old were only 5.5%. The 100% participants were all Level 400 students. Regarding specialisation, JHS Education had the largest percentage of 44.7%, followed by Primary Education (32.3%) and Early Grade Education (23.0%).

4.1 Reliability Analysis Results

Reliability through internal consistency was performed using Cronbach's alpha. The purpose of the reliability test was to see whether the items in each construct were consistently measuring what they should (Tavakol & Dennick,

2011). The table below indicates that all three constructs achieved Cronbach's alpha values above the minimum requirement of 0.70. More specifically, Generative AI Usage achieved a Cronbach's alpha value of 0.797 with five items, The value of Cronbach's alpha for Digital Competence was 0.837 with five items, while the value of Cronbach's alpha for Mathematics Teaching Effectiveness was 0.859 with five items as shown in table 2 below.

Table 2: Reliability values of the study item

Construct	Cronbach's Alpha	Number of Items
Generative Ai Usage	0.797	5
Digital Competence	0.837	5
Mathematics Teaching Effectiveness	0.859	5

Source: field data, 2026

4.2 Exploratory Factor Analysis (EFA)

Table 3 shows the output of Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO measure of sampling adequacy was 0.901, which is higher than the threshold value of 0.60. Thus, the size of the sample was adequate to conduct the factor analysis (Sigudla & Maritz, 2023). In addition, Bartlett's test of sphericity was significant, $\chi^2(105) = 1320.912$, $p < 0.001$. Hence, the correlation matrix differs from the identity matrix (Arsham & Lovric, 2011). Moreover, the determinant value of 0.002 indicates that multicollinearity did not exist between the items (Kim, 2019). The fact that the extracted factor accounted for more than 50% of the variance implies that the items adequately represented the construct.

Table 3: Exploratory Factor Analysis Results

Measurement items	Component		
	1	2	3
MTE2	.752		
MTE3	.667		
MTE1	.663		
MTE4	.652		
MTE5	.626		
DC4		.703	
DC3		.683	
DC5		.678	
DC2		.645	
DC1		.563	
GAIU5			.702
GAIU1			.691
GAIU4			.599
GAIU2			.598
GAIU3			.529
Total Variance Explained			50.810%
Extraction Method: Principal Axis Factoring.			
Rotation Method: Varimax with Kaiser Normalization.			
a. Rotation converged in 5 iterations.			

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.901
Bartlett's Test of Sphericity	Approx. Chi-Square	1320.912
	df	105
	Sig.	0.000
	Determinant	0.002

Source: field data, 2026

4.3 Confirmatory Factor Analysis (CFA)

Table 4: Confirmatory Factor Analysis

Model Fit Indices: CMIN = 21.090; DF = 24; CMIN/DF = 0.879; CFI = 1.000; TLI = 1.006; RMR = 0.020; RMSEA = 0.000; PClose = 0.963; GFI = 0.980		
AVE=0.544	CR=0.698	CA=674
GAIU5	Mathematics instructional content or activities were tailored to fit students of various abilities through the use of AI generation	0.859
GAIU1	Generative AI was applied by me to prepare mathematics lesson plans	0.592
AVE=0.546	CR=0.782	CA=0.782
DC5	Using digital technology, I can assess learners' knowledge in mathematics and give them constructive feedback.	0.780
DC4	I am able to effectively utilize digital technologies in mathematics instruction.	0.716
DC3	I can design or modify digital resources to suit the educational requirements of my mathematics students.	0.718
AVE=0.577	CR=0.845	CA=0.845
MTE5	I am capable of assessing my learners' comprehension of mathematics and giving them useful feedback.	0.732
MTE3	I get students to participate in activities that help them explain and defend their thinking mathematically.	0.769
MTE2	Use of examples and representations to enable students gain mathematical understanding.	0.800
MTE1	My explanations about mathematics topics are clear and easily understandable to the learners.	0.736

Source: field data, 2026

From the results of the CFA test in table 4, it can be stated that there is an excellent fit of the measurement model to the observed data. The chi-square (CMIN) statistic was found to be 21.090 with 24 degrees of freedom, leading to a chi-square to degree of freedom ratio (CMIN/DF) of 0.879 that is less than 3.0, the critical level (Alavi et al., 2020).

The values of comparative fit index (CFI) and Tucker-Lewis Index (TLI) were 1.000 and 1.006 respectively, suggesting that the model has excellent comparative fit with the data observed (Alavi et al., 2020).

Additionally, another proof that demonstrates the fit of the model is the root mean square residual (RMR), being equal to 0.020 and being much lower than the common benchmark of 0.08 (Alavi et al., 2020). In addition, the root mean square error of approximation (RMSEA) was 0.000, indicating the absence of any approximation errors. Also, the PClose value of 0.963 suggests the confirmation of hypothesis about close fit of the model. Lastly, the value of goodness-of-fit index (GFI) is 0.980, surpassing the benchmark of 0.90 (Alavi et al., 2020). Therefore, the conclusion is that CFA results demonstrate the fit of the measurement model.

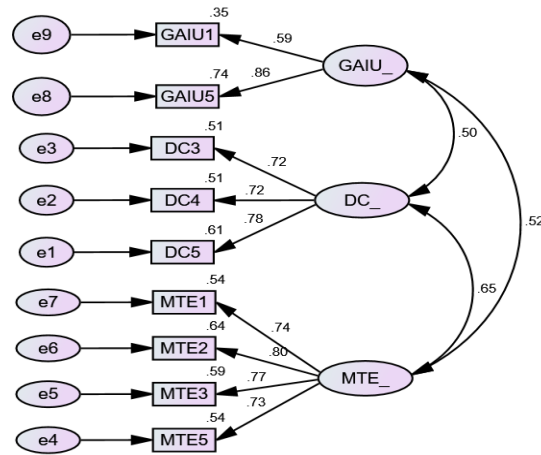


Figure 2: CFA Diagram

4.4 Discriminant Validity

Table 5: Discriminant Validity

Construct	GAIU	DC	MTE
GAIU	0.738	0.503	0.521
DC	0.503	0.739	0.655
MTE	0.521	0.655	0.760

Discriminant validity of the construct was established using the Fornell-Larcker criterion. It was determined that the square root of AVE was within the range of 0.738 to 0.760 and was higher than the correlations between the constructs ($r=0.503-0.655$) (Hamid et al., 2017). Hence, it is clear that the mentioned constructs are empirically different as shown in table 5.

4.5 Results of Path Analysis

Table 5: summary of hypothetical analysis results.

Path	β	CR	p-value
GAIU $\rightarrow$ MTE	0.181	2.577	0.010
DC $\rightarrow$ MTE	0.461	5.271	<0.001

Model Fit Indices: CMIN =21.090; DF =24; CMIN/DF =0.879; CFI =1.000; TLI =1.006; RMR =0.020; RMSEA =0.000; PClose =0.963; GFI=0.980;

Source: field data, 2026

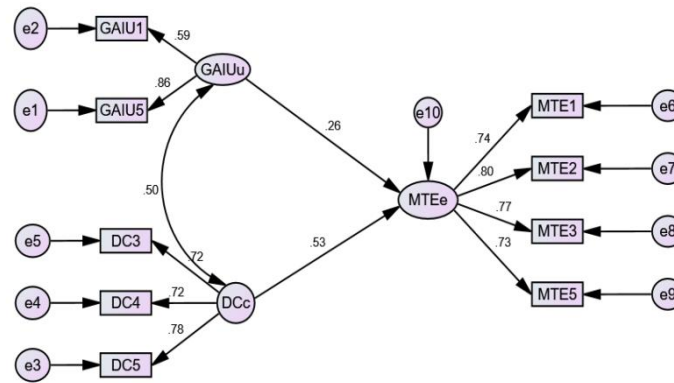


Figure 3: Path Diagram

5. Discussion of Findings

H₁: Generative AI Usage significantly predicts Mathematics Teaching Effectiveness among pre-service teachers.

It was found out that there is a positive correlation between Generative AI Usage and Mathematics Teaching Effectiveness of the pre-service teachers, thereby validating H₁. Based on the results ($B = 0.181$, $SE = 0.070$, $CR = 2.577$, $p = 0.010$), higher utilization of generative AI is associated with increased mathematics teaching effectiveness. The findings further validate the existing literature on the impact of generative AI in favor of pre-service teachers in preparing their lesson plans, instructional materials, tasks, and enhancing teaching materials (Blonder et al., 2024; Celik et al., 2025). Talking about the field of mathematics education, Gurl et al. (2024) suggested that ChatGPT can serve as a tool to plan lessons for pre-service secondary mathematics teachers, while Yanar and Ergene (2025) identified the affordances of generative AI in 5E mathematics lesson planning.

Such positive correlation identified in the current study can be attributed to the ability of generative AI to widen the range of instructional tools for pre-service teachers. The use of generative AI will enable the teachers to use a number of examples and problems on math, to set differentiating assignments, to explain math notions differently, and even generate formative assessment questions and feedback (Liu et al., 2026; Redmond-Sanogo et al., 2025). In a similar way, Rutherford et al. (2025) found that AI-enabled math classes contained more motivational components of instruction and feedback, along with odd examples.

However, the finding does not necessarily mean that the adoption of AI technology will always yield effective mathematics instruction. According to the literature review, there is a possibility that there may be errors in the mathematical content delivered through AI and also inappropriate recommendations offered by the AI technology (Hsu et al., 2024; Lee & Song, 2024). This means that it is important for teachers to use their professional judgment. In addition, Gasaymeh (2026) pointed out that the utility of generative AI technology in the educational field depends on the effectiveness of evaluation and integration of AI-generated materials by teachers. This is the reason why the relationship found in this study is strong and positive. H₁ was therefore supported.

H₂: Digital Competence significantly predicts Mathematics Teaching Effectiveness among pre-service teachers.

The results also suggest that Digital Competence plays an important and positive role in the Mathematics Teaching Effectiveness, hence H₂ is also supported. From the findings ($B = 0.461$, $SE = 0.087$, $CR = 5.271$, $p < 0.001$), it means that pre-service teachers who are digitally competent have greater effectiveness in teaching mathematics. This finding corresponds to the definition of digital competence that is “the ability to select, evaluate, create, and integrate digital technologies and resources for teaching, learning, and assessment purposes” (Soliman, 2026). The key point when it comes to mathematics teaching is to be digitally competent since there are many decisions to make regarding representation, resources, and learners' background (Mariscal et al., 2023).

This finding is in line with the TPACK model that underlies the current research. According to TPACK, technology integration should be considered taking into account interaction between knowledge about technology, pedagogy and content. In other words, it is implied that mathematics teachers should not only know how to work with different

digital devices but also know how those devices can be used to convey mathematical knowledge (Hidayat et al., 2024; Yue et al., 2024). In this connection, one should underline the focus of Akkoç and Dede (2019) on the significance of integration of technological knowledge and mathematical content and pedagogy in the field of mathematics teaching. Therefore, the strong connection between the Digital Competence and Mathematics Teaching Effectiveness shows that pre-service teachers with high digital competence can make pedagogically meaningful decisions regarding the use of technologies.

Significantly, Digital Competence showed a higher standardized path coefficient ($\beta = 0.461$) than that of Generative AI Usage ($\beta = 0.181$). Such a result indicates that the concept of digital competence may be more fundamental in teaching mathematics technologically. The reasoning aligns with the definition provided in the literature on the difference between GenAI usage and digital competence in which GenAI usage refers to what teachers do with the generative AI, while digital competence refers to the general ability of teachers to use digital technologies critically and efficiently (Guillén-Gámez et al., 2026). Hence, just having access to the generative AI could be not enough if pre-service teachers lack digital competence. H_2 was confirmed.

6. Conclusion

The results of this study prove that the Generative AI Usage as well as Digital Competence are strong positive predictors of the Mathematics Teaching Effectiveness among future teachers, thus proving both research hypotheses. Despite the important role played by generative AI in the development of lessons, the development of educational materials, and the representation of mathematical concepts, it is evident that digital literacy is the major determinant of the success of teaching mathematics. Therefore, it is obvious that the successful implementation of technologies in the context of mathematics lessons is not only based on the availability of the AI resources but also on the assessment of these resources.

6.1 Recommendations

Considering that the findings indicate that Generative AI Usage and Digital Competence positively predict Mathematics Teaching Effectiveness among pre-service teachers, the following recommendations could be considered:

1. Foster digital literacy in teacher education institutions: There is need for digital competence training in mathematics education programs in teacher education institutions to ensure that teachers can use digital resources effectively.
2. Generative AI Usage: The educational institutes should make sure that students are taught how to use Generative AI responsibly so that they can critically evaluate what is generated by the AI and adjust it accordingly for the needs of learners.
3. Integrate AI-assisted lesson planning in practice: It is important for mentors and mathematics tutors to motivate pre-service teachers to include the use of generative AI in their lesson plans and in creating instructional materials.
4. Ensure access to digital technology and AI systems: Education institutions should ensure access to the internet, digital platforms for learning, and adequate AI technology that will ensure technology-enabled mathematics education during teaching practices. This is consistent with the importance of technology-enabled educational instruction noted by the research.
5. Continuous learning for teachers should be promoted; the teachers of mathematics teachers should plan training sessions and workshops on current trends in technology that may be incorporated into teaching, like AI generation.

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