The Effect of Using MatGPT on Mathematical Proficiency among Undergraduate Students

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***Abstract*—This study aimed to investigate the effect of using MATLAB application that provides users with convenient access to OpenAI's ChatGPT (MatGPT) on mathematical proficiency among undergraduate students enrolled in the Differential Equation Course. The quasi-experimental design was used. The sample consisted of 94 students, distributed into three groups: two experimental groups and one control group. The researchers developed a mathematical proficiency test of verified validity and reliability containing 5 essay questions. The study results showed statistically significant differences between the mean scores of students' mathematical proficiency, in favor of the Artificial Intelligence (AI)-supported experimental group. The adjusted means for traditional teaching, teaching using programming language and interactive environment developed by MathWorks (MATLAB), and teaching using MatGPT in terms of Conceptual Understanding, Procedural Fluency, Strategic Competence, and Adaptive Reasoning were as follows: (70.69, 27.63, 75.04), (38.4, 48.61, 63.76), (14.18, 29.11, 34.24), and (32.12, 42.06, 49.02), respectively. Overall, the adjusted means for the mathematical proficiency strands were 40.22, 50.49, 59.03, respectively. Based on these findings, the researchers recommend encouraging faculty members to integrate AI applications, such as MatGPT, into mathematics teaching. Additionally, they suggest conducting further studies to explore faculty members' attitudes toward using MatGPT in education.**

***Keywords*—mathematical proficiency, Artificial Intelligence (AI), MatGPT, university students, faculty members, Jordan**

I. Introduction

Smart technology, in general, and AI applications, in particular, are no longer entertainment tools or secondary supplements to the teaching and learning processes. They have become a living reality and an urgent necessity in light of the recent digital transformations caused by the Corona pandemic (COVID-19) and subsequent school and university closures. These changes have significantly impacted global education systems in different countries. The role of smart technology in reducing educational loss has become critical, leading to a competitive race among smart digital technology experts, culminating in various AI models like Chat Generative Pre-Trained Transformer (ChatGPT).

ChatGPT is a form of neural language processing, designed to create interactive texts that simulate human work. It can perform tasks in a human-like brain, such as understanding and analyzing language, recognizing faces and voices, interpreting big data, and thinking independently. Through training, it can replicate human behavior [1]. Moreover, it can engage in dialogues on various topics, generate data to answer users' questions and create files [2].

At the university level in teaching mathematics, AI apps can greatly help determine students' learning levels, identify errors and their sources, choose teaching methods, solve problems, and present material in different scenarios that consider individual differences and enhance the quality of teaching [3].

AI has created a new reality in mathematics teaching for teachers and students. Teachers' roles have shifted from information transmitters to facilitators and designers of AI-supported learning environments. However, students have become independent learners and knowledge seekers, obtaining feedback according to their progress and performance [4].

Mathematics learning environments have transformed from group learning settings to individualized web-based, student-centered learning environments making mathematics learning easier through personalized instruction [5].

Since the announcement of ChatGPT, digital media have highlighted its significance as an unpredictable technological innovation. Despite prior AI coverage, ChatGPT's emergence has heightened interest in the opportunities and challenges it presented due to its unpredictable capabilities [6].

ChatGPT maintains a continuous dialogue style with users, simulating reality beyond merely providing answers to questions. This distinguishes it from other AI models due to its provided services in performing various tasks such as providing scientific content, translating texts, and answering users' questions [7, 8].

Studies have shown ChatGPT's functional performances such as creating content on specific topics [9], making suggestions [10], translating languages [11], preparing assessment tasks such as tests and exercises that help teachers evaluate students' learning [12], and assessing students' performance to save teachers' time for other teaching duties [13].

Given its development of a language close to human speech, ChatGPT has gathered wide attention [14]. It achieved significant success two months after its announcement [15], passing separate tests at the University of Minnesota Law School [16] and excelling in history. Researchers interested in mathematics education have explored using modern digital technologies in teaching. The National Council of Teachers of Mathematics (NCTM) identified a specific principle for integrating technology in mathematics teaching [17]. Integrating technology in teaching mathematics requires teachers to understand its concepts and skills [18]. Teachers' deep knowledge of content affects how they represent it to students to facilitate their learning [19].

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Research into the effectiveness of ChatGPT and its impact on academic achievement and developing mathematical thinking skills has become a broad area for continuous inquiry, with ChatGPT since it has become a hot topic due to its ability to perform mathematical problems and provide learning suggestions. A study by Xuan-Quy and Ngoc-Bich [20]. showed that ChatGPT is an effective teaching tool for mathematics, capable of handling drawn data and addressing the challenges posed by more difficult questions. However, accuracy dropped to 10% on more challenging questions, while it reached 83% for simpler computational tasks and 70% for comprehension levels.

Students need different levels of understanding and proficiency, such as knowing basic mathematical concepts and reading data and figures to solve difficult problems. Understanding progress levels to higher cognitive skills, analysis, and synthesis, enabling the collection of necessary information to solve problems. This requires a comprehensive assessment of ChatGPT's ability to solve mathematical problems or provide appropriate assistance [20].

Some studies have examined ChatGPT's efficiency in solving mathematical problems. Kortemeyer [21] found that ChatGPT makes many misconceptions and errors similar to those of novice students in calculus. On the other hand, some researchers view ChatGPT as a revolutionary tool for teaching and learning mathematics [6].

The American National Research Council launched the Mathematical Proficiency Project to encompass all aspects of mathematical expertise and knowledge for all students [22]. Mathematical proficiency includes integrated abilities: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition [23, 24].

Mathematical proficiency is defined as the conscious use of mathematical concepts, processes, and skills to connect mathematics to daily life and solve problems [25]. It involves students' confidence in their ability to perform mathematical procedures, solve, justify, and interpret problems, recognizing their importance and practical benefits [26]. It is an integrated network of abilities and relationships to connect elements of mathematical knowledge for the fluent execution of operations and algorithms [27]. Students' ability to transfer learning effects to various life contexts and subjects requiring mathematics [28].

To measure students' proficiency and ability in mathematical skills, it is necessary to use a performance assessment, which is designed to assess the student's knowledge, skills, and abilities in solving real-life problems [29].

Studies have highlighted the importance of developing mathematical proficiency components [30, 31]. Mohammed's [32] revealed the effectiveness of web technologies in developing mathematical proficiency. Since mathematical proficiency relies on students' performance quality in understanding concepts, executing mathematical operations and algorithms, and their confidence in solving and justifying problems, it revolves around the students' role.

Some studies have shown that artificial intelligence applications improve logical-mathematical thinking, however, teachers' perceptions of the importance of AI applications vary. Many believe that using these applications faces significant challenges related to teacher training and data privacy [33, 34]. Few studies have investigated the impact of using MatGPT on mathematical proficiency among undergraduate students, which justifies conducting this study.

ChatGPT is different from MatGPT since it is embedded within MATLAB, providing seamless, real-time assistance tailored to MATLAB workflows. MatGPT integrates directly with MATLAB to simplify tasks such as solving equations, debugging codes, and optimizing algorithms. Users with no prior programming experience can navigate and use the platform effectively through immediate feedback and guidance on the MATLAB-specific syntax and commands. The embedded approach ensures contextual precision in problem-solving by eliminating the need to switch between tools.

One of the unique features of MatGPT is its ability to assist users in solving differential equations step-by-step, providing immediate feedback at every stage and connecting solutions to real-life scenarios. This iterative support enhances user understanding and ensures progress through complex problem-solving processes. As a specialized and practical extension of ChatGPT, MatGPT simplifies MATLAB usage and provides targeted assistance, enhancing mathematical proficiency and making MATLAB more accessible and effective.

This study aimed to investigate the effectiveness of using MatGPT on mathematical proficiency among undergraduate students.

It acquires significance by tackling a subject that is currently receiving a lot of attention. On the other hand, AI has invaded the education sector, and its benefits and threats to the educational process are yet to be discovered. Moreover, it will provide students with skills that have the potential to either favorably or negatively affect their learning.

II. Literature Review

Studies on the effect of using AI applications in teaching mathematics such as a study by Tashtoush *et al*. [35]. They conducted it to explore mathematics teachers' perceptions of AI-based applications implemented by schools. The sample consisted of 580 male and female mathematics teachers from public and private schools in Abu Dhabi. It followed a descriptive-analytical approach. The study's results revealed that AI can be used as an educational tool to facilitate the teaching process and to improve students' performances by integrating AI systems and applications into the curricula. Additionally, the results proved that such integration contributed to increasing motivation for learning, challenges, competition, and excitement among students while considering individual differences.

The findings also highlighted the main obstacles that math teachers face when using AI systems and applications. The most significant of these were the pressures that prevent the use of AI in the classroom and the requirement for more work than traditional techniques when utilizing various applications. Additionally, the results revealed no statistically significant differences in the opinions of math teachers about the value of integrating AI tools and systems into the classroom. However, there were statistically significant differences regarding the challenges faced by math teachers while implementing AI in their teaching practices, due to their educational qualifications, particularly among teachers holding master's degrees.

Dokaly and Aldwibi's study [34], aimed to explore the types of AI applications and their impact on the development of logical-mathematical intelligence among students. Furthermore, it aimed to uncover the challenges of integrating such applications into education. The researchers analyzed available data on student performance in various educational environments. The results showed that through follow-up and tailored assistance, AI apps provide chances to improve logical-mathematical intelligence. However, there are still issues with training and data protection, and concerns about how well these applications enhance mathematical comprehension.

Tashtoush *et al*. [36] aimed to investigate the impact of Information and Communication Technologies (ICT) on the eleventh-grade female students' enthusiasm towards learning mathematics in a secondary school in the United Arab Emirates during the first semester of (2020–2021). The researchers chose to use a quasi-experimental methodology at a school with the necessary facilities for ICT-based education, in which two classes were randomly assigned as control and experimental groups. The instrument of the study was the Mathematics Academic Enthusiasm (MAE) questionnaire, with three subscales: cognitive, behavioral, and emotional. The results of the study revealed that the ICT-based education method had a more significant impact on students' MAE for the cognitive and behavioral subscales in comparison to traditional educational methods. However, there was no significant impact found on the emotional subscale, due to the use of the ICT-based education method.

As for the study of Hidajat *et al*. [37], it examined the effect of digital technology learning, guided discovery, and self-regulated learning strategy, on mathematical creativity. The study used a Learning Management System (LMS) incorporating guided discovery and self-regulated learning strategies to address these issues. The study sample consisted of 67 high school students in Malang. The study results showed that digital learning technology based on guided discovery and self-regulated learning strategies, positively impacted students' mathematical creativity during online learning. The increased implementation of digital learning technology based on these strategies increased students' mathematical creativity.

Al-Oufi and Al-Ruhaili's study [33] sought to investigate the possibility of using artificial intelligence to foster high school students' mathematical creativity from the viewpoint of Saudi Arabian female instructors and its correlation with certain characteristics. The sample consisted of 150 female teachers. The findings revealed that the level of mathematics teachers' awareness of the importance of using artificial intelligence applications was moderate. The study also found that using AI applications presents several challenges. Furthermore, statistically significant differences were found in female teachers' perceptions of the importance of using artificial intelligence applications, attributed to variables such as academic qualifications, experience, and the number of training courses in using technology.

Al-Farani and Al-Hujili [38], aimed to identify factors affecting teachers' use of AI in education. The descriptive-analytical method was used, and the study was conducted on 446 teachers in Egypt. The results showed that teachers' acceptance of using AI applications in education was high, with expected performance being the most influential factor, followed by expected effort, social influences, and available facilities. The results indicated statistically significant differences in teachers' estimates attributed to gender, favoring female teachers. However, the results showed no statistically significant differences in their estimates due to age, experience, or specialization.

Studies on the impact of ChatGPT on mathematical achievement are still limited. Other researchers have examined different aspects of ChatGPT's role in mathematics. For instance, Frieder *et al.* [39] analyzed ChatGPT's mathematical capabilities using the manually created GHOSTS database. The analysis included testing various skills necessary for professional mathematics practice that AI models could simulate, such as answering arithmetic questions, completing mathematical proofs with missing information, and solving complex questions like those in mathematics Olympiads. The experimental results showed that ChatGPT's mathematical capabilities are significantly lower than those of an average graduate student in mathematics, where ChatGPT often understands the question but does not provide correct solutions.

Xuan-Quy and Ngoc-Bich [20] conducted an analytical study on ChatGPT's mathematical abilities in answering multiple-choice and open-ended questions in a Vietnamese secondary school. The study showed that ChatGPT performed well on simple questions but less on more complex and comprehensive ones. The researchers concluded that ChatGPT may be a useful tool to enhance learning rather than a substitute for teachers.

AI apps have become a reality in education across various scientific fields, including diverse physical applications and mathematical applications [40]. By using deep neural networks to meet conditions for solving differential equations, High-dimensional partial differential equations, including Burgers' and Hamilton's equations, were used to evaluate the technique and show neural networks' ability to solve them [41]. Deep neural networks were also used in the numerical analysis of partial differential equations [42]. These studies focused on utilizing applications in solving differential equations as purely mathematical operations rather than employing AI applications in the teaching process itself.

However, studies exploring the impact of AI apps on teaching differential equations, and enhancing mathematical thinking and proficiency remain limited, if not rare. This represents a rich domain for research and study. Moreover, previous study samples were chosen from first-year university students, however, this study focused on second or third-year university students. Furthermore, this study distinguishes the presence of ChatGPT as an implicit tool within Math Lab; it provides students with the ability to use Math Lab without the need for any prior knowledge of programming, in addition to the ability to directly obtain assistance if the student encounters any problem related to Math Lab. Thus, this study aims to explore the effect of teaching differential equations through the employment of AI apps on mathematical proficiency.

A. Statement and Null Hypothesis

In the coming years, mathematics education will require creating a rich learning environment in mathematical concepts, enabling students to engage with its evolving dynamics and continuous advancements [43]. Mathematical proficiency is one of the most prominent concepts, as the National Research Council (NRC) has emphasized ensuring mathematics education within the school curriculum through the "Mathematical Proficiency" project. This initiative aims to enhance students' expertise, competence, and mathematical knowledge [22].

Mathematical proficiency comprises an integrated set of capabilities, including Conceptual Understanding, Procedural Fluency, Strategic Competence, Adaptive Reasoning, and Productive Desire [23, 24]. Furthermore, the National Council of Teachers of Mathematics (NCTM) has stressed the importance of integrating technology into mathematics instruction, establishing specific principles for employing modern digital tools to achieve this objective [17].

Several studies have emphasized the need to develop components of mathematical proficiency among students [30, 31], highlighting that mathematical proficiency requires students to possess diverse levels of understanding and competence. This includes conceptual and procedural knowledge, the ability to interpret data and diagrams, higher-order thinking skills, and the capability to gather information essential for problem-solving.

Mohammed's study [32] demonstrated the effectiveness of web-based technologies in fostering mathematical proficiency. Similarly, research by Xuan-Quy and Ngoc-Bich [20] identified ChatGPT as an tool for teaching mathematics, excelling in handling data, equations, and symbols, and addressing complex questions. ChatGPT has thus been regarded as a revolutionary tool in mathematics education [6], with enhancing mathematical proficiency. However, Kortemeyer [21], noted that ChatGPT is prone to conceptual errors similar to those carried out by students.

MATLAB has greatly improved mathematical competency by offering an interactive environment that facilitates students' profound comprehension of mathematical ideas. The program facilitates the application of analytical tools and simulations to investigate various solutions to mathematical issues, promoting critical and creative thinking. MATLAB facilitates the conversion of abstract concepts into tangible visual applications, enhancing student engagement and motivation, strengthening problem-solving abilities, and reinforcing the practical comprehension of complex mathematical topics [44].

As they observed and conversed with students about differential equations, the present study's researchers have noted a decline in students' understanding of concepts related to solving these equations, a weak ability to distinguish related concepts and low procedural fluency. Additionally, students have shown difficulty in translating real-life problems into differential equations. This highlights the need to investigate the effectiveness of integrating technological tools such as MATLAB and ChatGPT in interpreting differential equations to enhance mathematical proficiency. Thus, this study aims to explore the impact of using these tools on students' abilities to solve differential equations and improve their mathematical proficiency through the integration of ChatGPT within MATLAB.

The problem of the study lies in examining the effect of using MatGPT in developing mathematical proficiency among university students at a Private Jordanian University.

B. The Research Question

Are there any statistically significant differences at the level (α = 0.05) between the means of mathematical proficiency due to the method of solving differential equations; (MatGPT, MATLAB, or traditional approach)? The following null hypothesis was formulated:

There are no statistically significant differences at the level (α = 0.05) between the means of mathematical proficiency attributed to the method of solving differential equations; (MatGPT, MATLAB, or traditional approach).

C. Materials and Methods

The study adopted an experimental methodology with a quasi-experimental design for control and experimental groups to examine the effects of solving differential equations using MatGPT on the mathematical proficiency of undergraduate students. Three groups were examined for three weeks, one as a control group and two as experimental groups. The control group was taught to solve differential equations using the traditional method of paper and pen, while the first experimental group was taught to solve the same differential equations using MATLAB, and the second experimental group was taught to solve differential equations using MatGPT. The quasi-experimental design of this study is illustrated as shown in Fig. 1.

CG	O1	-----	O1
EG1	O1	X1	O1
EG2	O1	X2	O1

CG	Control Group (Traditional)
EG1	Experimental Group1(MATLAB)
EG2	Experimental Group2(MatGPT)
X1	Solving Differential equation using MATLAB approach
X2	Solving Differential equation using MatGPT approach
-----	Solving Differential equation using traditional approach
O1	Mathematical proficiency test (pre – Posttest)

Fig. 1. Study design.

D. Participants

This study was conducted on a purposeful sample upon availability sample of undergraduate students enrolled in the differential Eq. (1) course at a Private Jordanian university. The sample consisted of 94 students enrolled in the Differential Equation course, divided into three groups: (MatGPT, MATLAB, and traditional method). Three groups were randomly assigned, with the first group comprising 28 students as the control group, and There were 33 students in each of the two experimental groups.

E. Procedural Definitions

Conceptual Understanding: The capacity of students to define mathematical concepts, differentiate them from unrelated ideas, comprehend the numerous connections between them, identify mathematical generalizations and their connections, and apply them in a variety of problem-solving situations.

Procedural Fluency: Refers to the student's ability to perform mathematical operations and execute calculations with ease, skill, and accuracy. It includes knowing the correct methods and techniques for solving mathematical problems and using various approaches to solve a mathematical problem.

Strategic Competency: The students' ability to reframe and model a mathematical problem in different ways, such as using symbols, equations, tables, or graphs, and determining the appropriate strategy to solve the mathematical problem and applying it effectively.

Adaptive Reasoning: The ability of a student to think logically and flexibly in different mathematical situations, interpret results, and adapt to information while solving mathematical problems.

Mathematical Proficiency: The student's ability to deal with various mathematical situations and solve mathematical problems effectively and flexibly. It encompasses conceptual understanding, procedural fluency, strategic competency, and adaptive reasoning.

F. Data Collection

A test consisting of five differential equations was developed to measure mathematical proficiency. Students in the three groups were asked to solve each of these equations by answering fourteen steps (Table 1). Also, a quantitative assessment scale was used to measure conceptual understanding, procedural fluency, strategic competency, and adaptive reasoning, in addition to the overall level of mathematical proficiency, as shown in Table 2. Moreover, each step in Table 2 corresponds to an indicator in the mathematical proficiency scale, according to Table 3, and the student's answer to each of these steps indicates their level of possession of the corresponding indicator.

Table 1. Mathematical proficiency test

	Soluation Steps for Each Equation
1	Cu1: Determine the type and order of this equation
2	Sc1: Rewrite the equation in an easier way
3	Cu2: Write the mathematical idea you need to solve this equation
4	Cu3: Give an example of how this equation will be applied in real life
5	Cu4: Find another differential equation whose solution steps are similar
6	Sc2: Sort the necessary data and ignore the redundant ones
7	Pf2: Predict a solution
8	Cu5: Show the steps for solving the equation using a table, a figure and a diagram
9	Pf1: Summarize the steps in the solution
10	Pf3: Write a suitable algorithm to solve this equation
11	Sc3: Identify any special numerical causes used by this equation to generalize the solution
12	Ar1: Describe your solution in general
13	Ar2: Based on your knowledge of differential equations, interpret your solution
14	Ar3: According to your solution, draw the conclusions

The mathematical proficiency scale (shown in Table 2) was presented to a group of experts specialized in measurement, evaluation, and mathematics curricula and teaching methods. They determined the relative weights of the mathematical proficiency measurement indicators and their fields, as well as the scale's levels and weights. A five-point scale instrument was used and arranged from the lowest to the highest level; (low level, acceptable level, intermediate level, good level, and finally high level). Each scale reflecting mathematical competence levels was given a relative weight based on the cumulative weight: with 20% representing the lowest level, 40% representing the acceptable level, 60% representing the intermediate level, 80% representing the good level, and 100% representing the high level. Regarding the relative weights of the indicators of mathematical proficiency, it was decided by the experts at the level of each indicator according to how important it was to solve the differential equation until it reached its final form.

G. Teaching Methodology

The study was conducted in the second semester of the academic year 2023/2024. In the traditional group, differential equations were taught through lectures using a whiteboard or printed materials, the instructor explained theoretical concepts, mathematical methods, and real-world applications of differential equations. The students followed step-by-step instructions and took notes as they solved equations. Each student practiced problems on their own, with the instructor providing direct feedback and clarification during class. Structured learning emphasizes problem-solving skills without relying on artificial intelligence or software.

Another group of students used MatGPT to interact with differential equations and learned to solve them. MatGPT explains the reasoning process and analytical methods behind solving differential equations step-by-step. As students engaged in guided conversations, they received hints and immediate feedback while solving problems. Equations were entered into MatGPT for analysis, verification, and comprehension of each step. By using artificial intelligence-guided assistance, this approach emphasizes the exploration of conceptual learning.

The second experimental group focused on MATLAB's for solving differential equations. Students wrote scripts to solve equations and visualize results, such as plotting solution curves, during hands-on coding sessions. Through practical exercises, students enhanced their programming skills while reinforcing their understanding of differential equations through computational methods. A two-hour workshop was held for teachers before the study began on how to solve differential equations using MatGPT, along with the implementation of how to correct students' answers using a mathematical proficiency rubric.

H. Validity and Reliability

To test the content validity, a focus group was formed, which included mathematics faculty members at Jordanian universities, experts in mathematics education in addition to measurement and evaluation specialists. They received mathematical proficiency measurement indicators, a pre-and post-test, and a quantitative assessment scale. They were asked to judge them and make comments in terms of the validity and accuracy of the mathematical content tests, the applicability of the solution steps, the comprehensiveness and accuracy of the indicators and their ability to measure mathematical proficiency, the extent to which the indicators belong to their fields, in addition to verifying the validity and accuracy of the alignment between the indicators and the steps for solving the differential equation specified in the test. Finally, they were asked to verify the validity of the quantitative rubric, based on their feedback, some criteria in the scoring rubrics were modified until they reached their final form. The reliability of the specified computational method in measuring the level of mathematical proficiency was modified based on the feedback submitted by the focus group.

Table 2. A scale of mathematical proficiency strands

Mathematical proficiency (MP) Dimensions	Relative weight	MP-Indicators	Mathematical Proficiency Scale					MP-Post Intervention
			low level	Acceptable level	intermediate level	Good level	High level	
			20%	40%	60%	80%	100%	
Conceptual Understanding (CU)	CU1	20						*
	CU2	20						*
	CU3	20						*
	CU4	20						*
	CU5	20						*
	CU-OVERALL				100			**
Procedural Fluency (PF)	PF1	35						
	PF2	30						
	PF3	35						
	PF-OVERALL				100			
Strategic Competence (SC)	SC1	35						
	SC2	30						
	SC3	35						
	SC-OVERALL				100			
Adaptive Reasoning (AR)	AR1	35						
	AR2	30						
	AR3	35						
	AR-OVERALL				100			
Mathematical Proficiency (MP)					100 (400/4)			***
*	(Relative Weight) × (Level Percentage for Post−Intervention)							
**	$MP = \sum_{CU1}^{CU5} (\text{MP Post−Intervention})$							
***	$MP = \sum_{CU}^{AR} (\text{MP Post−Intervention})/4$							

Table 3. Mathematical proficiency indicators

Mathematical Proficiency (MP) Dimensions	Mathematical Proficiency Indicators	
	Number	Indicators
Conceptual Understanding (CU)	CU1	Understanding the concepts associated with differential equations and their relationships (ordinary differential equations, partial differential equations, order of differential equations).
	CU2	Solving differential equations by integrating mathematical ideas.
	CU3	Integrating differential equation concepts with their applications.
	CU4	Identifying and recalling the rules and procedures learned previously and required to solve differential equations.
	CU5	Representing differential equation solving procedures mathematically (tables, figures, diagrams).
Procedural Fluency (PF)	PF1	Implementing the steps necessary to solve differential equations in a flexible and precise manner.
	PF2	Predicting the solution of differential equations according to the procedures followed and the related concepts.
	PF3	Applying appropriate algorithms to solve differential equations.
Strategic Competence (SC)	SC1	Rewriting the differential equation in a more understandable manner.
	SC2	Identifying the necessary data and ignoring the redundant information.
	SC3	Investigating specific numerical cases in order to arrive at a general solution.
Adaptive Reasoning (AR)	AR1	Explaining and justifying the solutions obtained
	AR2	Analyzing the relationships between knowledge about differential equations and their solution logically
	AR3	Showing how the differential equation solutions can be used to draw conclusions.

Cooper's coefficient was used to assess the reliability of the post-test of mathematical proficiency. Cooper's coefficients across individuals and overtime were 0.91, 0.94. A random sample of answer sheets was re-corrected by the researchers and the correlation between the corrector and the researchers was calculated to determine the reliability of the test correction. There was a high correlation coefficient 0.95, which indicated that the correction mechanisms were reliable. Additionally, to confirm the consistency of the rubrics, they were examined again, separated by one week. After comparing each evaluator's findings separately, Cooper's equation was used to get the agreement coefficient, which came out to be 0.92.

I. Research Procedures

To implement the study, the following stages were as follows:

- Formulating indicators to measure mathematical proficiency: The indicators were developed by reviewing literature related to mathematical proficiency [22, 45, 46]. The number of indicators to measure mathematical proficiency was fourteen indicators distributed over four domains, with five indicators to measure conceptual understanding, and nine indicators distributed equally to measure procedural fluency, strategic competence, and adaptive reasoning, respectively.

- Aligning indicators with steps to solve differential equations: Fourteen steps were formulated that the student must answer to solve each equation. Each step measures the extent to which the student possesses each of the indicators used to measure mathematical proficiency.
- Designing a quantitative assessment scale for correcting students' answers: On this scale, students' mathematical proficiency was measured as a whole as well as in each of the four domains.
- An assessment of pre-mathematical proficiency: used five differential equations designed according to the second stage. The level of pre-mathematical proficiency was calculated using the quantitative assessment scale developed in the third stage.
- In the implementation stage: students were given a variety of differential equations with varying degrees and types, and they were trained to solve them using the approaches specified for each group (MatGPT approach, MATLAB approach, or the traditional approach).
- Measuring the level of post-mathematical proficiency: All students in all groups were required to solve five differential equations following the fourteen steps provided in Table 1 after completing the study experiment for the three groups. A specially designed answer booklet was used to solve the differential equations. Teachers then corrected each student's answers to each differential equation and monitored her level of mathematical proficiency in solving them according to the rubric (Table. 2). Overall, mathematical proficiency and its domains represent the average of the student's grades in the five differential equations.

J. Data Analysis

Means and standard deviations analyzed students' performance on both pre- and post-tests of their mathematical proficiency. Additionally, a multivariate analysis of Covariance (MANCOVA) with Wilks' Lambda was utilized to examine the significance of differences in overall mathematical proficiency means and its four levels; (Conceptual understanding, procedural fluency, strategic, and adaptive reasoning), after isolating any potential effect of pre-test performance. The significance of differences between the means of mathematical proficiency between each pair of groups was examined using post-hoc comparisons. Further, the Etta square (η^2) was also calculated.

III. Results and Discussion

Results related to the null hypothesis**,** Table 4, and Fig. 2 show the means and standard deviations for the overall score and the score for each strand of mathematical proficiency according to the teaching method.

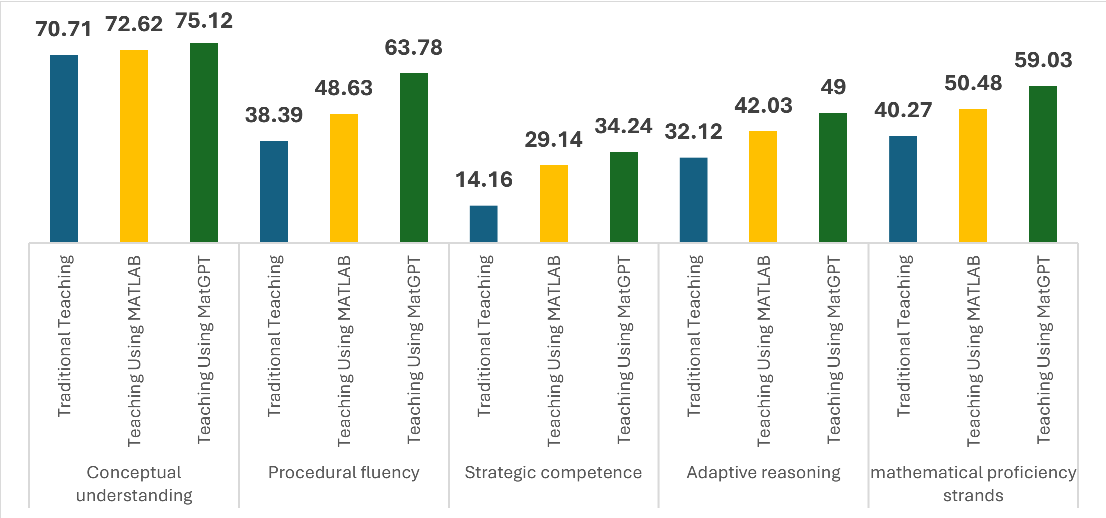

Fig. 2. Means of post-mathematical proficiency strands according to teaching methods.

Table 4. Means and standard deviation in mathematical proficiency strands according to teaching methods

mathematical proficiency strands	Teaching Method	No of students	Pre-intervention1001		Post-intervention100	
			Means	S. D	Means	S. D
Conceptual understanding	Traditional Teaching	28	51.42	15.90	70.71	33.19
	Teaching Using MATLAB	33	31.02	17.66	72.62	29.77
	Teaching Using MatGPT	33	37.78	19.62	75.12	29.44
Procedural fluency	Traditional Teaching	28	51.42	15.90	38.39	23.91
	Teaching Using MATLAB	33	31.02	17.66	48.63	28.90
	Teaching Using MatGPT	33	37.78	19.62	63.78	26.43
Strategic competence	Traditional Teaching	28	51.42	15.90	14.16	13.32
	Teaching Using MATLAB	33	31.02	17.66	29.14	32.85
	Teaching Using MatGPT	33	37.78	19.62	34.24	33.12
Adaptive reasoning	Traditional Teaching	28	51.42	15.90	32.12	12.03
	Teaching Using MATLAB	33	31.02	17.66	42.03	21.59
	Teaching Using MatGPT	33	37.78	19.62	49.00	22.18
Mathematical Proficiency Strands	Traditional Teaching	28	51.42	15.90	40.27	17.58
	Teaching Using MATLAB	33	31.02	17.66	50.48	26.15
	Teaching Using MatGPT	33	37.78	19.62	59.03	24.51

Table 4 and Fig. 2 indicate a difference between the mean scores of students' responses to the post-test on mathematics proficiency. The overall mean score on the mathematical proficiency test for students who studied differential equations using AI-supported MATLAB (MatGPT) was MatGPT = 59.03. In terms of mathematical proficiency dimensions, the mean scores were as follows: conceptual understanding = 75.12, procedural fluency = 63.78, strategic competence = 34.24, and adaptive reasoning = 49.00. In contrast, students who studied differential equations using MATLAB without AI support received an average score MATLAB = 50.48, with scores as follows for the dimensions: conceptual understanding = 72.62, procedural fluency = 48.63, strategic competence = 29.14, and adaptive reasoning = 42.03. As for the students who studied differential equations using the traditional method, their mean score on the mathematical proficiency test was Traditional = 40.27, with the following averages for the dimensions: conceptual understanding = 70.71, procedural fluency = 38.39, strategic competence = 14.16, and adaptive reasoning = 32.12.

To determine the significant differences between means, a Multivariate Analysis of Covariance (MANCOVA) with Wilks' Lambda was performed following a test to determine the homogeneity of variances. Results indicate a homogeneity in mathematical proficiency and its dimensions: conceptual understanding, procedural fluency, strategic competence, and adaptive reasoning. Table 5 provides the results of the MANCOVA with Wilks' Lambda.

Table 5. MANCOVA of the mathematical proficiency strands according to teaching methods

Source of Variation	Wilks lambda	Fe	Sig	Etta Square**
Teaching Methods	0.66	5.12	0.0001*	0.22

0.01 – 0.06: Weak, 0.07 – 0.13: Medium, 0.14 and more: Strong [47].

As shown in Table 5, statistically significant differences were observed in the means of the sample respondents' responses to the overall mathematical proficiency test, as well as within each of its dimensions: conceptual understanding, procedural fluency, strategic competence, and adaptive reasoning ($F = 5.124$, $p \leq 0.05$). Further, the effect size was substantial (0.223), indicating that the teaching method has a significant impact on mathematical proficiency as a whole. According to Dunst's study [47], this effect size is considered large. Table 6, illustrates the effects of teaching methods on all four dimensions of mathematical proficiency: conceptual understanding, procedural fluency, strategic competence, and adaptive reasoning.

Table 6. MANCOVA of the study groups in the mathematical proficiency strands

Source of Variation	mathematical proficiency strands	Sum of Squares	Df	Means of Squares	F-Value	Sig	Etta Square
Pre-mathematical proficiency strands	Conceptual understanding	8657.51	1	8657.51	9.63	0.001*	0.18
	Procedural fluency	15470.79	1	15470.79	28.44	0.001*	0.28
	Strategic competence	22417.95	1	22417.05	37.05	0.001*	0.32
	Adaptive reasoning	32412.14	1	22511.16	24.13	0.001*	0.44
	Total	13876.84	1	13876.81	34.38	0.001*	0.46
Teaching Methods	Conceptual understanding	3208.6	2	1604.35	1.79	0.174	0.11
	Procedural fluency	20303.97	2	10151.98	18.66	0.001*	0.23
	Strategic competence	18664.97	2	1332.39	15.42	0.001*	0.26
	Adaptive reasoning	19224.19	2	8392.12	16.67	0.001*	0.33
	Total	13443.83	2	6721.91	16.65	0.001*	0.36
Error	Conceptual understanding	80889.15	90	898.76			
	Procedural fluency	48947.04	90	1241.19			
	Strategic competence	54462.15	90	605.14			
	Adaptive reasoning	44521.78	90	701.12			
	Total	36325.01	90	403.61			
Adjusted Total	Conceptual understanding	89929.078	93				
	Procedural fluency	74448.138	93				
	Strategic competence	83402.03	93				
	Adaptive reasoning	81214.66	93				
	Total	55532.85	93				

Table 6 indicates that the null hypothesis was rejected since there was a significant difference between the students' overall mathematics proficiency test scores, which was attributed to the teaching methods (solving differential equations using MatGPT, solving differential equations using MATLAB, and solving differential equations using traditional methods) ($F = 16.65$, $p \leq 0.05$). The effect size was 0.36, indicating that the teaching method had a significant impact on students' mathematical proficiency in solving differential equations, as 36% of the variance in differences in students' mean scores in mathematical proficiency was caused by the teaching method.

In terms of conceptual understanding, the results showed that the teaching method had no significant impact on students' understanding of differential equation concepts ($F = 1.79$, $p \leq 0.05$). Approximately 11% of the variance in the differences in students' mean scores for conceptual understanding was attributable to the teaching method, which had an effect size of 0.11.

The results also revealed statistically significant differences between the mean scores of students in procedural fluency attributed to the teaching method (solving differential equations with MatGPT, solving differential equations with MATLAB, and solving differential equations with traditional methods) ($F = 18.66$, $p \leq 0.05$). With an effect size of 0.23, the teaching method had a significant impact on students' procedural fluency in solving differential equations, with 23% of the variance in the differences in students' mean scores attributable to the teaching method.

Moreover, the results showed statistically significant differences between the mean scores of students in strategic competence, which is attributed to the teaching method (solving differential equations using MatGPT, solving differential equations using MATLAB, and solving differential equations using traditional methods) ($F = 15.42$, $p \leq 0.05$). Accordingly, the effect size of 0.26 indicates that the teaching method had a significant impact on students' strategic competence in solving differential equations, with 26% of the variance in students' mean scores in strategic competence attributable to the teaching method.

The results further confirmed that there were statistically significant differences between the mean scores of students in adaptive reasoning attributed to the teaching method (solving differential equations using MatGPT, solving differential equations using MATLAB, and solving differential equations using traditional methods) ($F = 16.67$, $p \leq 0.05$). Students' adaptive reasoning in solving differential equations was significantly affected by the teaching method, with 33% of the variance in the differences in students' mean scores attributable to the teaching method.

Based on the adjusted mean scores after controlling pre-test performance, Table 7 presents the post-hoc pairwise comparison of the three groups to determine the influence of the teaching method on the overall mathematical proficiency as well as its dimensions, that showed statistically significant differences: procedural fluency, strategic competence, and adaptive reasoning.

Table 7. LSD Test comparisons among the adjusted means in the mathematical proficiency strands

mathematical proficiency strands	**Teaching Method**	**No of students**	**Adjusted Mean**	**Traditional Teaching**		**Teaching Using MATLAB**	
				Means Diff	Sig	Means Diff	Sig
Conceptual understanding	Traditional Teaching	28	70.69				
	Teaching Using MATLAB	33	27.63	–43.06	0.22		
	Teaching Using MatGPT	33	75.04	4.35	0.02*	47.41	0.09
Procedural fluency	Traditional Teaching	28	38.40				
	Teaching Using MATLAB	33	48.61	10.21	0.01*		
	Teaching Using MatGPT	33	63.76	25.36	0.00*	15.15	0.02*
Strategic competence	Traditional Teaching	28	14.18				
	Teaching Using MATLAB	33	29.11	14.93	0.00*		
	Teaching Using MatGPT	33	34.24	20.06	0.00*	5.13	0.00*
Adaptive reasoning	Traditional Teaching	28	32.12				
	Teaching Using MATLAB	33	42.06	9.94	0.02*		
	Teaching Using MatGPT	33	49.02	16.9	0.04*	6.96	0.03*
Mathematical proficiency strands	Traditional Teaching	28	40.22				
	Teaching Using MATLAB	33	50.49	10.27	0.03*		
	Teaching Using MatGPT	33	59.03	18.81	0.00*	8.54	0.00*

In Table 7, statistically significant differences are shown between the mean scores of students on the overall post-test for mathematical proficiency in favor of the group that used MATLAB to solve differential equations, compared to the group that used the traditional method. Furthermore, the table indicates statistically significant differences between the mean scores of students on the overall post-test for mathematical proficiency for those students who learned how to solve differential equations using MatGPT as compared to those students who learned how to solve differential equations using the traditional method. Additionally, the table indicates that statistically significant differences were observed between the mean scores of students on the overall post-test for mathematical proficiency for the group that learned to solve differential equations using MatGPT and the group that learned to solve differential equations using MATLAB, in favor of those who learned using MatGPT.

As for conceptual understanding, the table indicates that there are no statistically significant differences between the mean scores of solving differential equations using MATLAB and traditional methods and MatGPT in this area. In contrast, the mean scores of students' responses for those who learned to solve differential equations using MatGPT differed statistically significantly from those who solved differential equations using traditional methods in favor of those who learned to solve differential equations using MatGPT.

In the areas of procedural fluency, strategic competence, and adaptive reasoning in solving differential equations. The table shows statistically significant differences between the mean scores between each pair of (solving differential equations using MatGPT, using traditional methods), (solving differential equations using MatGPT, solving differential equations using MATLAB), and (solving differential equations using MATLAB, solving differential equations using traditional methods), in favor of (solving differential equations using MatGPT, solving differential equations using MatGPT, solving differential equations using MATLAB), respectively.

A. *Broader Implications of the Study*

The use of AI apps in teaching raises several challenges, which subsequently require multifaceted solutions such as: training teachers to use AI apps and platforms effectively and ethically (e.g, Cognii, Acadly, and ALEKS), providing the right environment, creating convictions among teachers and providing incentives to encourage them to implement AI tools, and Digital education and information security to protect their data.

B. Implication

The mathematical proficiency of students who solved differential equations using MatGPT was higher than that of those who solved differential equations using the traditional method and MATLAB. MatGPT provides students with step-by-step instructions, real-time feedback, and personalized learning experiences, concentrating on understanding rather than automation as in MATLAB [48]. Visualization tools, enhance engagement with mathematical theory by demonstrating alternations and stability in solution behavior [49]. MatGPT can also generate programming code directly, eliminating the gap between conceptual learning and practical implementation [50]. Compared to traditional methods, MatGPT allows students to explore different solutions while focusing on conceptual learning [51].

Students who solve differential equations using MatGPT have a similar conceptual understanding to a student who solves differential equations using traditional methods or MATLAB. This is because all students have previously studied the concept of differential equations in the same way during calculus courses they have previously taken. Chen *et al*. [52] and McCauley *et al*. [53] found that AI tools enhance student engagement and confidence and provide personalized feedback, facilitating learning and correcting misconceptions, but they are not sufficient in themselves to acquire algebraic mathematical concepts. Moreover, AI does not significantly enhance a strong conceptual understanding of differential equations in comparison to traditional methods [54, 55].

Students who solved differential equations with MatGPT demonstrated greater procedural fluency than those who used traditional methods or MATLAB because MatGPT, as an AI-based tool, allows students to interact more dynamically with problems, enhancing their understanding and fluency through iterative learning and error correction. In contrast, traditional methods and MATLAB often require students to rely on predefined algorithms and manual inputs, providing less interactive problem-solving support [56]. Studies have shown that AI-based tutoring systems like MatGPT significantly improve mathematical procedural fluency, since they can adjust to individual learning paces and provide immediate feedback, which is essential for mastering complex concepts like differential equations [13].

MATLAB with ChatGPT (MatGPT) can offer real-time feedback, direction, and dynamic problem-solving techniques to improve procedural fluency. Traditional MATLAB approaches force students to depend mostly on their prior knowledge of coding and reference materials, which might lead to gaps in their comprehension of the sequential procedures required to solve differential equations. Rather, MatGPT helps students understand how their solution works, optimize code, and troubleshoot mistakes step-by-step. By empowering students to confidently execute calculations and build their procedural knowledge, interactive help promotes fluency. Additionally, by combining MATLAB results with natural language explanations, an intuitive link between mathematical theory and computational practice is established, enabling students to complete tasks precisely and understand the underlying ideas.

Students who used MatGPT to solve differential equations exhibited a higher level of strategic competency than those who used traditional methods or MATLAB. This can be attributed to MatGPT's ability to provide instant feedback and adaptive learning pathways that enhance engagement and understanding [57]. Additionally, MatGPT encourages critical thinking and problem-solving skills by diversifying teaching approaches [58] and allowing students to explore multiple solution strategies and reinforce their learning [59]. Alternatively, traditional methods may limit students' exposure to diverse problem-solving approaches, resulting in a superficial understanding of the material [60]. MatGPT can, therefore, significantly enhance students' strategic competencies in solving differential equations by integrating AI technologies.

MatGPT and MATLAB have different impacts on mathematical proficiency, particularly in terms of strategic competence. MatGPT excels in fostering strategic competence by offering personalized, real-time feedback, which helps students refine their problem-solving strategies. Its interactive, step-by-step guidance encourages students to explore multiple approaches and reflect on their solutions, supporting the development of flexible, conceptual problem-solving skills. The tool's ability to simplify complex problems and contextualize them in real-world situations enhances students' understanding and encourages self-reflection, making it especially effective for beginners or intermediate learners.

On the other hand, MATLAB focuses more on computational tasks, making it stronger for advanced applications in mathematics, engineering, and applied fields. However, its reliance on algorithms and programming may hinder the development of strategic competence, particularly for novice learners. While MATLAB excels in solving complex problems, it provides limited real-time feedback and does not encourage exploration of alternative problem-solving strategies as effectively as MatGPT. As a result, MatGPT is better suited for cultivating strategic thinking and flexibility in problem-solving, while MATLAB is more appropriate for students who are already proficient in basic mathematical concepts and looking to apply them in more advanced contexts.

Students who solved differential equations using MatGPT demonstrated higher adaptive reasoning skills than those who used traditional methods or MATLAB. MatGPT's interactive and responsive learning environment allows students to receive immediate feedback and adjust their solution strategies in real time [57]. MatGPT can simulate various different scenarios of critical and adaptive thinking, fostering a deeper conceptual understanding of math [60]. Traditional methods lack dynamic feedback for developing adaptive reasoning skills, which may restrict students to a linear approach to problem-solving [59]. Students' adaptive reasoning abilities can be significantly enhanced by integrating AI-driven tools like MatGPT into differential equation solving. MatGPT simulates a conversational learning environment, which may explain students' superior adaptive reasoning skills. In contrast to traditional methods or MATLAB, MatGPT engages students in interactive question-and-answer sessions that mimic the guidance of a tutor. Through this approach, students improve their ability to think critically, recognize mistakes, and comprehend differential equations.

Additionally, MATLAB and MatGPT work together to support adaptive reasoning by encouraging a deeper understanding of mathematical concepts and exploring alternative paths to solutions. While traditional techniques limit students to predetermined ways, MatGPT's conversational AI provides insight into a variety of problem-solving methodologies. Flexibility is crucial to developing logical and flexible reasoning about differential equations. MatGPT fosters an adaptive mindset by presenting hypothetical scenarios and simulating real-world applications. Combining MATLAB and ChatGPT is a powerful tool that enhances reasoning and procedural fluency in the classroom.

Implementing MatGPT in mathematics education offers exciting possibilities, but it comes with notable challenges that need careful consideration. One key issue is the accuracy and reliability of AI tools. While these systems are trained to solve complex problems, they can sometimes produce incorrect solutions or explanations, which could lead to misunderstandings among students and reduce trust in technology. Additionally, accessibility challenges arise from the digital divide, in which not all students have equal access to the devices or reliable internet needed to use these tools effectively. Language barriers also pose difficulties, particularly in regions where the AI does not support local languages or dialects, potentially excluding some learners.

Another significant concern is the risk of over-reliance on AI for problem-solving. While MatGPT can provide instant answers, this might discourage students from developing their critical thinking and manual problem-solving skills. Teachers, too, may struggle with the transition to using AI tools in their classrooms, especially if they lack adequate training or feel resistant to adopting new methods. Without proper guidance, the integration of MatGPT may not achieve its full potential and could even disrupt existing teaching practices.

Privacy and ethical issues further complicate the implementation of AI in education. MatGPT relies on collecting and analyzing user data, which raises concerns about data security and compliance with privacy regulations. Addressing these concerns requires forming ethical frameworks and transparent practices in the design of AI tools.

The financial and technical aspects of adopting MatGPT also pose challenges. Developing, maintaining, and scaling AI systems can be expensive, making it difficult for schools with limited budgets to adopt technological applications. Technical limitations, such as software bugs or incompatibility with certain platforms, could disrupt the learning process and diminish the tool's effectiveness. These issues may require significant investments in infrastructure and ongoing support, which might not be feasible for all educational institutions.

Lastly, the use of AI tools like MatGPT can affect student motivation and engagement. The lack of human interaction when relying on AI may reduce opportunities for collaborative learning and meaningful teacher-student relationships.

MatGPT is generally perceived as an engaging and supportive tool for learning mathematics by students. With MatGPT, students receive immediate, personalized feedback, which helps build motivation and reduce math anxiety. The step-by-step instructions and interactive nature of the tool are especially appreciated, as they provide clarity and encourage students to explore problems at their own pace. In addition, the ability to receive targeted assistance based on individual needs fosters a sense of personalized learning, particularly for students who may struggle in a traditional classroom.

Some students, however, express concern about becoming too reliant on the tool, fearing that it will hinder their ability to think independently. While MatGPT excels at supporting basic and intermediate problems, it struggles with more complex, conceptual challenges, leading some students to question its effectiveness. Overall, students recognize the importance of balancing MatGPT's use with opportunities for independent critical thinking and problem-solving, despite its reputation as an invaluable resource for boosting confidence and understanding.

C. Limitations and Determinations

The study was limited to undergraduate students studying basic mathematics and teaching courses in the first semester of the academic year 2023/2024. The type of instruments used in the study and their psychometric properties determine the generalization outcomes.

The sample was restricted by several factors such as the geographical region, higher education system, and university regulations which do not allow for a completely random sample. So, these factors and others could influence the generalizability of the findings. However, the results of this study provided valuable insights related to mathematical proficiency aspects, which requires taking it into account when applying AI apps in other mathematical subjects or when applying it to educational materials other than mathematics. To address these limitations, future research may choose a larger sample, to validate these findings to support generalization.

In light of these results, the researchers recommended:

- Guiding faculty members to employ AI applications in teaching mathematics.
- Conducting further studies on faculty members' beliefs and perceptions about using MatGPT in teaching mathematics.
- Conducting further qualitative studies on faculty members' beliefs about using MatGPT in teaching mathematics.
- Conducting longitudinal studies to assess MatGPT's effects on learning retention, skill-development, and progression in mathematics over time.
- Investigate adaptive learning systems leveraging MatGPT for tailored support to diverse learners, including those with special needs or advanced abilities.
- Combine MatGPT with VR/AR and embed it in LMS platforms for enhanced interactivity, immersion, and progress tracking.
- Discuss ethical concerns like equity and dependency while evaluating teacher preparedness and professional development for effective integration.

IV. Conclusion

This study identifies the significance of using AI applications in mathematics teaching as evidenced by the finding that there was a significant difference in solving differential education in favor of GPT compared with MATLAB or traditional method.

This study contributes to the body of knowledge by investigating the use of AI applications, specifically MatGPT, in developing mathematical proficiency.

It provides empirical evidence on the potential benefits and challenges of integrating AI in mathematics education, offering insights for educators, policymakers, and technology developers.

The findings of this study revealed a significant effect of using AI apps on solving differential equations, which might indicate a potential effect on other subjects beyond mathematics, such as physics, chemistry, and biology. Further, their use is particularly evident in medical sciences, where advanced robotics are employed for disease diagnosis and precision in surgical operations.

Additionally, they could be used in other fields such as humanities in analyzing texts, correcting spelling and grammar, and facilitating translation.

On the other hand, the impact of AI apps on developing modern teaching methods and enhancing students' self-directed learning could be explored further to achieve sustainable development goals and lifelong learning. Moreover, AI apps can also provide adaptive learning environments tailored to the needs of individuals with disabilities.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS CONTRIBUTIONS

IAHE wrote the introduction, the problem of the study, the literature review, and the methodology. Moreover, he supported the interpretation of the research findings; AAST developed the research idea by identifying the problem and designing the study. He plays a key role in treatment, collecting data, and interpreting the research findings; SYAAH played a key role in editing, reviewing the paper several times, and formatting it according to the template; all authors approved the final version.

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