Integrating Chat-GPT in the Classroom: A Study on Linear Algebra Learning in Higher Education

Dilham Fardian[1,2], Didi Suryadi[1,2,*], Sufyani Prabawanto[1,2], and Al Jupri[1]

[1]Department of Mathematics Education, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Indonesia
[2]Indonesian Didactical Design Research Development Center (PUSBANGDDRINDO), Universitas Pendidikan Indonesia, Indonesia
Email: dilhamfardian@upi.edu (D.F.); didisuryadi@upi.edu (D.S.); sufyani@upi.edu (S.P.); aljupri@upi.edu (A.J.)
*Corresponding author
Manuscript received September 13, 2024; revised October 14, 2024; accepted December 14, 2024; published April 15, 2025

***Abstract*—The transition to higher education often presents considerable challenges for students in mastering linear algebra, particularly due to its abstract nature and increased complexity compared to secondary education curricula. Chat Generative Pre-trained Transformer (Chat-GPT) has the potential to mitigate these challenges by providing tailored support that enhances students' conceptual understanding. This research aims to investigate the integration of Chat-GPT as a supplementary educational tool to enhance linear algebra learning experience. Study participants included mathematics education students aged 20–23 in three Indonesian universities who had completed an elementary linear algebra course. The study employed both quantitative and qualitative methodologies. Quantitatively, this study utilized a quasi-experimental design and a meta-analysis. The experimental groups included students who received instructions solely through Chat-GPT and those in which Chat-GPT was used in conjunction with a mathematics expert. The Chat-GPT version 3.5 was used for the experimental groups, while the control group was taught using conventional instructional methods. Qualitatively, hermeneutic phenomenology was used to understand students' perspectives on technology in education. The findings indicated that Chat-GPT can provide step-by-step explanations for solving math problems and make mathematics learning more engaging and accessible. Although technology represents a valuable asset in enriching the educational experience, educators' roles as a facilitator, elucidator, and guide remains indispensable. Therefore, it is recommended that Chat-GPT be used in education primarily for teaching fundamental concepts, while instructors remain heavily involved in explaining more abstract linear algebra concepts.**

***Keywords*—Analysis of Variance (ANOVA), Artificial Intelligence (AI), Chat-GPT, meta-analysis, phenomenology**

I. Introduction

The 21st century is frequently regarded as an era of technology [1, 2]. The swift development of technology has substantially and profoundly impacted multiple dimensions of human existence, including the education sector [3–7]. Although various technological tools have been integrated into education, the utilization of AI-driven platforms such as Chat-GPT remains relatively underexplored, particularly in the context of mathematics education. Given the increasing reliance on AI in various fields, it is crucial to understand how these platforms can be effectively leveraged to enhance students' learning outcomes, to improve conceptual understanding, foster critical thinking and serving as a tool to support students in independent learning. The Coronavirus Disease 2019 (Covid-19) pandemic marked a pivotal moment in the adoption of technology in the education sector [8]. Technology commonly features systematic arrangement, with structured elements to provide specific benefits [9]. These specific benefits include enhancing student engagement through interactive and multimedia content, delivering individualized educational experiences that address the specific needs of each student, improving accessibility to educational resources regardless of geographic location, and enabling more efficient assessment and feedback mechanisms. The application and adaptation of technology in learning have become necessary in the globalization era [10, 11]. Technology integration in education is anticipated to serve as a facilitator in achieving learning objectives and to streamline the process of accessing information and acquiring knowledge [12]. Considering the existing problems, this research focuses on the utilization of various AI-based tools in education and learning, with particular emphasis on Chat-GPT. This research endeavors to investigate the prospective application of Chat-GPT in linear algebra learning.

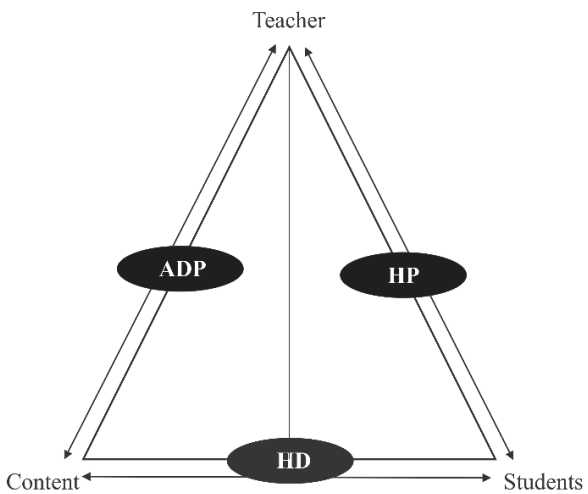


Fig. 1. Didactic triangle.

Chat-GPT was selected as an educational tool in this study for several reasons: Internally, Chat-GPT's Natural Language Processing (NLP) capabilities allow it to understand students' questions in their own language, making it more effective at addressing their specific needs. Additionally, Chat-GPT offers high accessibility by providing 24/7 access to learning resources, which is particularly beneficial for students who require assistance outside regular school hours. Externally, Chat-GPT is free and easily accessible on smartphones, making it a practical alternative to other educational tools, such as GeoGebra, which generally require a laptop for optimal use. This ease of access enables students to engage

with educational technology anytime and anywhere, thereby enhancing inclusivity.

According to Suryadi [13], technology is important in the diffusion and acquisition of knowledge. As teachers play a role in the diffusion process, students are the actors in the acquisition process, and the content being diffused or acquired is pre-existing knowledge resulting from the transposition processes. The didactic triangle concept is an interconnection among the three primary entities involved in events related to the diffusion and acquisition of knowledge [14]. Within the didactic triangle (See Fig. 1), each participant assumes a specific role in knowledge diffusion and acquisition, producing relationships that can be comprehensively explained from both the diffusion and acquisition perspectives [15].

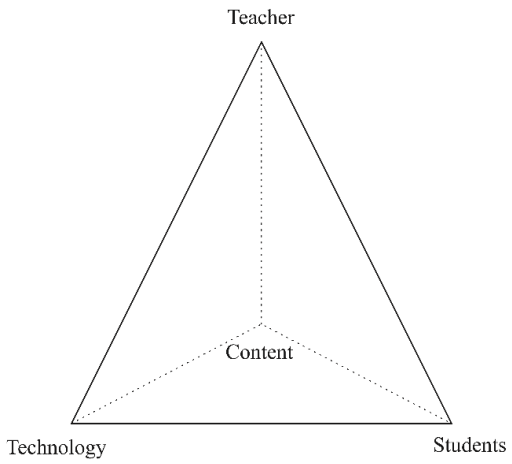


Fig. 2. Didactic tetrahedron.

The didactic triangle establishes a fundamental framework for comprehending the interplay among these three components, emphasizing the significance of a cohesive alignment to facilitate effective teaching and learning [16]. Therefore, it is unsurprising that the relationship between teachers, students, and learning materials in the didactic triangle raises a new question, "Can technology be integrated into the didactic triangle?". Technology has prompted a change in the didactic triangle concept, leading to the development of the didactic tetrahedron [17–19]. This conceptual shift places technology as an independent element within the educational framework. Fig. 2 illustrates the didactic tetrahedron as a development of the didactic triangle.

In a didactic tetrahedron, there are four interconnected triangles, each representing unique viewpoint regarding the role of technology in mathematics education. The triangles include the teacher-student-content triangle, the teacher-student-technology triangle, the teacher-content-technology triangle, and the student-content-technology triangle. Each triangle offers a distinct viewpoint on how technology influences the dynamics between teachers, students, and content in mathematics education [20]. Technology serves as extended cognition in the education process, allowing humans to enhance their cognitive abilities. In the didactic tetrahedron, technology functions as a catalyst to help teachers in their instructional methods, enable students in their learning journeys, and enhance the educational resources utilized during the teaching process [21]. There remains a shortage of teaching materials to adequately support the learning activities [22, 23]. However, one of the technologies that can help educators and learners understand learning materials and integrate them with the teacher-student-content dynamic in the didactic tetrahedron is Chat-GPT. Fig. 3 depicts the overlay visualization of Chat-GPT in mathematics education.

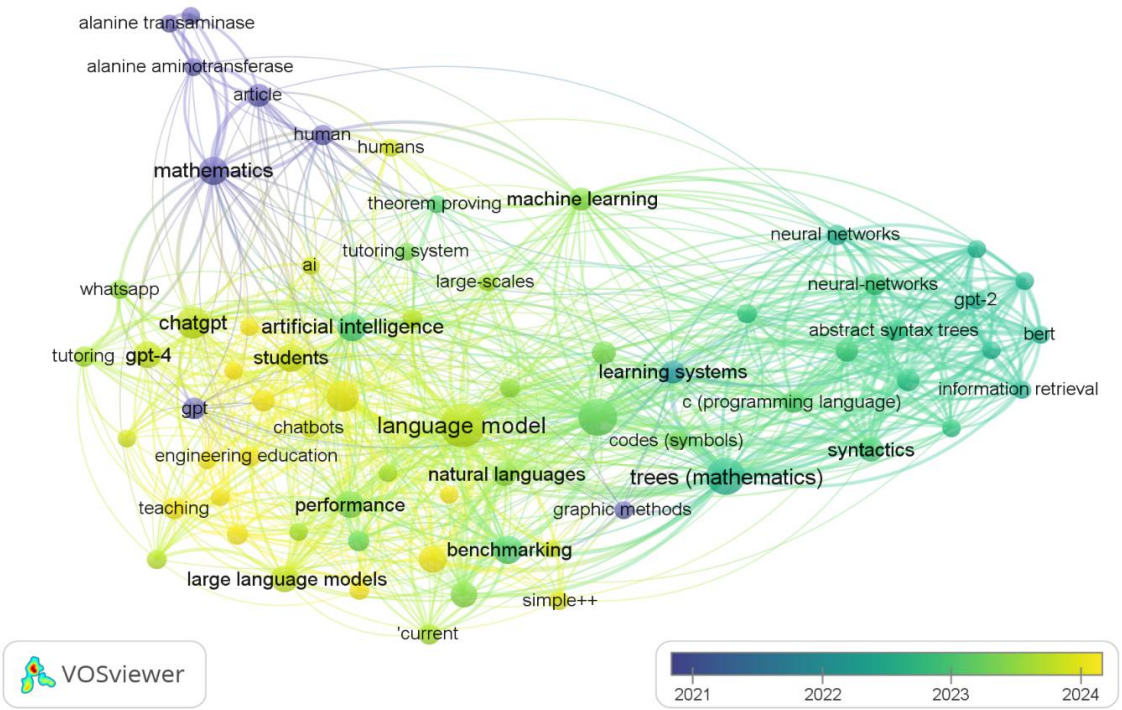


Fig. 3. Overlay visualization of Chat-GPT in education.

Chat-GPT is the current technology trend integrated into education and the opportunity to explore its utilization in education is immense. The potential of Chat-GPT extends beyond its general application as a language model. Notably, it demonstrates proficiency in performing mathematical reasoning, which opens up the possibilities of integrating

Chat-GPT into mathematics education within the classroom setting. By leveraging its problem-solving capabilities in mathematics, Chat-GPT has the potential to improve the quality of teaching and learning of mathematical concepts. As the researchers explored the intersection of Chat-GPT and mathematics education, it became evident that there is a substantial opportunity to harness Chat-GPT's capabilities for personalized and interactive learning experiences. The ability of Chat-GPT to assist in mathematical problem-solving could serve as a valuable asset for educators seeking innovative ways to engage students and reinforce mathematical concepts. Nevertheless, the connection between Chat-GPT and learning outcomes needs to be improved, highlighting a research gap in this study.

This study not only offers insights into the practical application of Chat-GPT in enhancing students' understanding of linear algebra but also highlights the broader implications of integrating AI tools in mathematics education. Such integration has the potential to revolutionize learning environments and transform traditional teaching paradigms by making abstract mathematical concepts more accessible, engaging, and personalized, thereby contributing to a more inclusive and effective education system. Accordingly, the researchers formulated two research questions that this study aimed to address as follows:

1) Is there a statistically significant contrast in mathematical performance among students who solely rely on Chat-GPT without guidance from an instructor, those who receive instructions aided by Chat-GPT, and those who receive conventional instructions without Chat-GPT's assistance?
2) What are students' opinions regarding the utilization of Chat-GPT in learning and understanding mathematical concepts?

II. Literature Review

A. Overview of Chat-GPT

Since its release in November 2022, the language model Chat Generative Pre-trained Transformer (Chat-GPT) has quickly gained recognition as a widely used question-and-answer dialogue system [24]. A publicly accessible tool developed by OpenAI, it is crafted to generate text that mimics human language by predicting the subsequent word in a sentence, relying on the context provided by previous words [25, 26]. This language model, known as Generative Pre-trained Transformer (GPT), is built on the foundation of a Pre-trained Large Language Model (LLM), which has been extensively trained on massive datasets to understand and generate human-like text. Subsequently, the model undergoes Supervised Fine-Tuning (SFT) and further optimization through Reinforcement Learning with Human Feedback (RLHF) to tailor its capabilities to specific tasks, such as delivering comprehensive responses tailored to specific prompts or instructions. An artificial intelligence system capable of generating responses to user input, Chat-GPT has transformed the dynamics of human-machine interactions and prompted a fundamental analysis of whether it can potentially replace the traditional role of teachers in the classroom [27, 28]. Chat-GPT is popular among a wide range of users [29]. In education, it can serve as a valuable tool to support students in their learning journey while simultaneously easing the workload of teachers. Moreover, Chat-GPT can produce responses similar to those of a human when given open-ended prompts, such as questions, statements, or academic-related topics [30]. Fig. 4 illustrates the stages of Chat-GPT as reinforcement learning with human feedback [31].

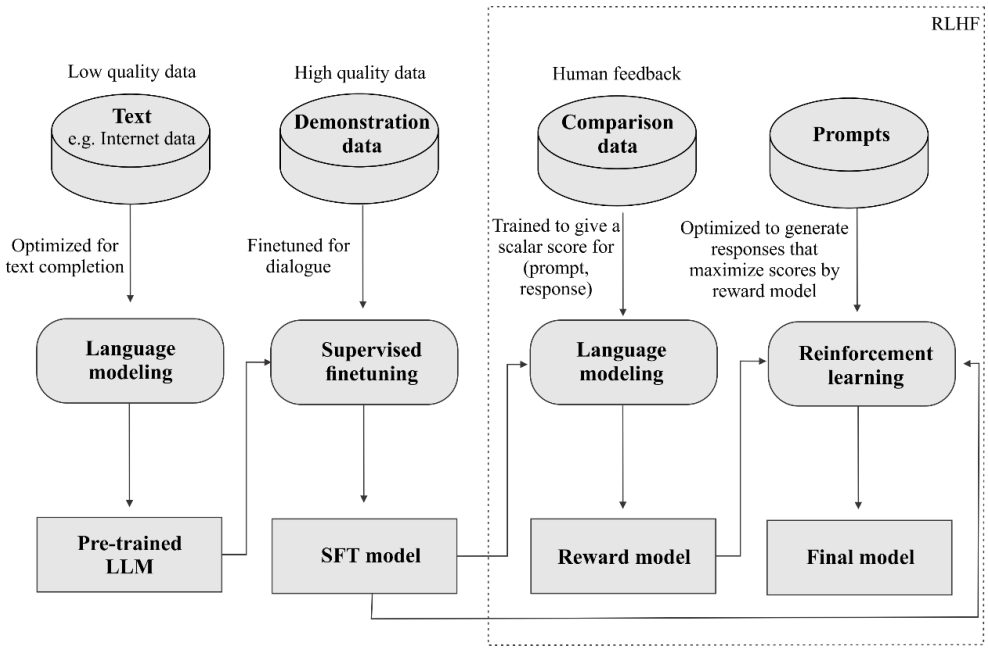


Fig. 4. Stages and elements involved in training a model similar to Chat-GPT.

B. Utilization of Chat-GPT in Education

As an emerging artificial intelligence technology, the extensive use of Chat-GPT in education has drawn considerable attention and stirred debates across different segments of society [32]. In a recent survey, Son [33] investigated the potential use of Chat-GPT in mathematics education for students and future teachers. The research found that Chat-GPT's analysis of students' problem-solving methods and mathematical reasoning was comparable to that

of mathematics education professionals. This aligns with the findings of Li *et al*. [34], who highlighted that Chat-GPT shows promising utility in various college-level mathematics courses, such as calculus, linear algebra, discrete mathematics, engineering mathematics, and introductory statistics. Lee *et al*. [35] also examined Chat-GPT's effectiveness in middle school mathematics, testing its accuracy using questions from Taiwan's past education exams. In the study, Chat-GPT achieved a high accuracy rate of 90% (A+). Unlike studies that focus on developing chatbots for individual courses or topics, the research demonstrated that Chat-GPT achieved over 80% (A) accuracy across six key areas of mathematics in Taiwan, indicating its potential to improve students' self-regulation skills and middle school mathematics education. In another study, Egara and Mosimege [36] explored how secondary school mathematics teachers view the integration of Chat-GPT into mathematics teaching. Their findings revealed that teachers who utilized Chat-GPT experienced positive results, including greater teaching efficiency, higher student engagement, and enhanced comprehension of difficult concepts.

In addition to mathematics, Chat-GPT is widely utilized across various fields, with significant implementations in healthcare (38.6%), computer science/Information Technology or IT (18.6%), and education/research (17.3%) [37]. Fig. 5 illustrates Chat-GPT's utilization across several fields.

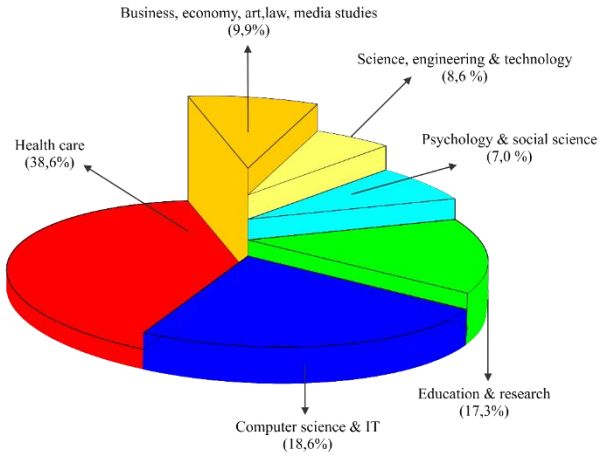


Fig. 5. Chat-GPT's utilization across various fields.

Despite the aforementioned benefits, some caution the use of Chat-GPT in the classroom. Wardat *et al*. [38] pointed out that Chat-GPT lacks a thorough understanding of geometry and struggles to effectively address misconceptions. The reliability of Chat-GPT's solutions depends on the complexity of the problem, the input data, and the quality of instructions provided. Similarly, Remoto [39] warned that AI models might produce incorrect answers or use unsuitable methods for problem-solving. Pardos and Bhandari [40] also highlighted the need for human oversight when using Chat-GPT, particularly in the absence of error mitigation strategies. Furthermore, it was revealed that nearly 89% of college students in the United States utilize Chat-GPT in completing their homework assignments. As many as 53% of these students use the tool primarily for writing papers; 48% of students reported using Chat-GPT during examinations; and 22% found the tool beneficial for generating paper outlines [41]. However, scholars have taken notice of the utilization of Chat-GPT in education. There are concerns that excessive reliance on AI might impede the complete development of analytical and critical thinking skills [42]. While Chat-GPT demonstrates significant potential as a learning tool, such as enhancing teaching efficiency, student engagement, and understanding of complex concepts, its limitations underscore the need for careful implementation and ongoing supervision in educational settings. These findings align with the study conducted by the researchers, emphasizing the importance of evaluating both the benefits and challenges of integrating AI tools such as Chat-GPT into educational practices. To fully harness Chat-GPT's potential as a learning tool, this research also presents clear guidelines that describe situations in which Chat-GPT can be safely used in the classroom, as well as addressing its limitations in reliability and the verification of the information it provides

III. Materials and Methods

A. Research Design

This study utilized two distinct methodologies: quantitative and qualitative research methods. The selection of both quantitative and qualitative methodologies was driven by the specific objectives aimed to achieve by this study. The quantitative approach was selected as it allows objective measurement and comparison of Chat-GPT's impacts on learning outcomes. While quantitative methods are effective for producing statistical measurements and numerical insights, they are limited in their ability to capture the complexity of personal experiences and interpretations. Consequently, to strengthen the findings of the study, a qualitative approach was integrated to gain a better understanding of how students engage with Chat-GPT, how they perceive the role of technology in their learning journey, and the challenges they face throughout the process. In qualitative methods, there is an ontological assumption that must be fulfilled in that the researcher and the subject are dependent on one another. Meanwhile, in quantitative research, the ontological assumption that must be met is that the researcher and the subject must remain independent. Therefore, the researchers intentionally avoided employing a mixed-methods approach due to the ontological belief that the contrasting assumptions make it technically impossible to combine the two methodologies.

This study employed a quasi-experimental design and meta-analysis combined with phenomenological analysis to explore the effectiveness of Chat-GPT in linear algebra learning. From the standpoint of quantitative research, the researchers employed two methods, namely the quasi-experimental design and the meta-analysis review. The methods were combined to draw a comprehensive quantitative conclusion by integrating two complementary perspectives: primary data obtained through a quasi-experimental approach and secondary data gathered through meta-analysis. The integration of primary and secondary data ensures that the conclusions are not based solely on the conditions of the current study but also applicable across a broader range of contexts, thereby strengthening the overall validity and reliability of the research. The quasi-experimental design proves particularly valuable when

conventional experimental designs are impractical or ethically challenging. The experimental groups of this study consisted of students who were taught using Chat-GPT version 3.5. In this study, there were two experimental groups. The first experimental group included students who exclusively received thorough instruction via Chat-GPT throughout their learning process. Meanwhile, the second experimental group involved students taught through the collaboration between Chat-GPT and an expert mathematics educator. In contrast, the control group comprised students taught through conventional learning methods. To meet the assumption of independence in quantitative research, both instructors entirely managed the experimental and control group classes.

In this study, the activities of the students who participated in the project were structured to align with the goals of the experimental design and to provide a comprehensive understanding of the integration of Chat-GPT into learning. In the first experimental group, students were given an introduction to Chat-GPT, including its features, capabilities, and how to interact with the tool effectively. Students worked on mathematical problems directly with Chat-GPT, receiving instant feedback and guidance. This activity allowed them to explore various problem-solving methods and understand different approaches to mathematical concepts. In the second experimental group, students received instruction through a combination of Chat-GPT and an expert educator. The educator provided contextual explanations, addressed misconceptions, and facilitated discussions, while Chat-GPT was used for practice and reinforcement. During these sessions, students worked on problem sets under the supervision of the educator, with Chat-GPT offering additional explanations and alternative solutions. In the control group, students attended regular lectures delivered by the educator. The lectures followed a traditional format, with the educator explaining concepts, demonstrating examples, and assigning homework.

The objective of meta-analysis is to combine and analyze research findings from multiple studies that have been conducted, specifically focusing on the integration of technology and mathematics education. By collecting and synthesizing data from previous research, a meta-analysis aims to provide a more comprehensive and robust overview of the effects of relationships between variables under investigation, specifically the impact of technology on students' learning outcomes. By combining data from multiple studies, a meta-analysis enhances statistical power and enables stronger generalizations. A meta-analysis serves as a potent tool to streamline and unify existing research outcomes, offering a broader and more robust perspective on the integration of technology within the didactic triangle.

From the qualitative research standpoint, this study adopted hermeneutic phenomenology to investigate students' perspectives on technology integration in education. This approach places a primary emphasis on understanding an individual's worldview rather than constructing explanatory laws [43]. Phenomenological research, as explained by Creswell [44], is meticulously crafted to examine the life experiences and subjective viewpoints of individuals. At its core, phenomenology is dedicated to exploring the phenomena that emerge within consciousness, highlighting the significance of grasping the intricate and distinctive qualities inherent in an individual's experiential landscape. Fig. 6 illustrates the research flow undertaken in the study.

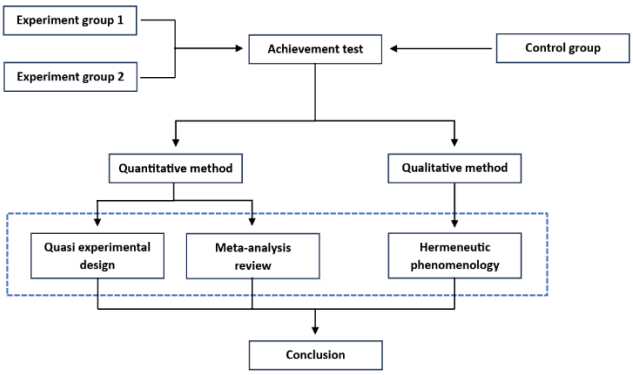


Fig. 6. Research flow diagram.

B. Sample and Data Collection

This study was conducted at three Indonesian universities, involving students aged 20–23 in the mathematics education department who had completed the elementary linear algebra course. This research focused on linear algebra learning since linear algebra has extensive applications in technology, particularly in the development of algorithms and mathematical modeling, which are foundational to various modern technological innovations.

To avoid bias in a study involving participants from three Indonesian universities with similar educational backgrounds, the researchers employed a stratified random sampling technique, in which the strata were determined based on the university. This method ensured comparability because it divided the population into subgroups (strata) based on key characteristics, including academic performance and gender, and subsequently randomly selected participants from each stratum. This approach helped ensure that each group was representative of the overall population and that the groups were similar in key aspects, reducing potential bias in the study. The total population of this study included 75 participants (first university: 10 participants, second university: 27 participants, and third university: 38 participants). These three universities, located on three major islands in Indonesia, were selected to represent a broader demographic and geographic diversity in Indonesia with the objective of capturing the perspectives of participants from different regions, each with its distinct educational, cultural, and social backgrounds. The researchers aimed to select a sample of 30 participants [45]. To determine the total of sample size, the researchers utilized the G*Power application. Table 1 presents the input and output parameters.

Table 1. Input and output parameters

Parameters	Input values	Output values
Input	Effect size f	0.6
	α err prob	0.05
	Power (1–β err prob)	0.80
	Number of groups	3
Output	Noncentrality parameter	10.800000
	Critical F	3.3541308
	Total sample size	30
	Actual power	0.80044441

Table 1 shows that with 30 participants distributed across three groups, the study met the desired power of 0.80.

Statistical power is typically set at 0.80 or 80%, indicating that there is a 20% chance of incorrectly accepting the null hypothesis, which corresponds to a beta value of 0.20 or 20%. In other words, there is a 20% risk of failure in detecting a true effect. Meanwhile, the number of participants to be selected from each university was determined using the proportional formula as follows:

$$n_i = \frac{N_i}{N} \times n \quad (1)$$

The sample of the study is as follows:

- First experimental group: 8 participants
  a) First university: 1 participant
  b) Second university: 3 participants
  c) Third university: 4 participants
- Second experimental group: 12 participants
  a) First university: 2 participants
  b) Second university: 4 participants
  c) Third university: 6 participants
- Control group: 10 participants
  a) First university: 1 participant
  b) Second university: 4 participants
  c) Third university: 5 participants

The meta-analysis review utilized in this study adhered to the procedures outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PRISMA-guided process included four stages: identification, screening, eligibility, and inclusion. Upon screening, 19 articles pertaining to the impact of technology on algebraic achievement were identified.

In applying the qualitative methodology, the research incorporated phenomenological method with in-depth interviews involving five students who recently incorporated Chat-GPT into their learning journey. Study participants were selected utilizing a blend of criterion sampling and snowball sampling methods, requiring participants to take part in the experimental classes integrated with Chat-GPT and their ability to thoughtfully and reflectively articulate their experiences.

C. Data Analysis

From the quantitative perspective, to evaluate the learning outcomes, a specifically developed post-test was administered to all participants. For this purpose, the researchers undertook a rigorous validation process. First, the test items were reviewed by subject matter experts to ensure content validity and alignment with the learning objectives. Additionally, the researchers conducted a pilot test with 10 participants to assess reliability and clarity of the questions (Cronbach's Alpha = 0.755). Based on the pilot feedback, revisions were made to improve the test's overall reliability and to ensure it accurately measured the intended outcomes. The post-test was designed to assess participants' understanding and application of linear algebra concepts after the intervention. The initial steps included calculating descriptive statistics such as mean, standard deviation, and frequency to aggregate the data and provide a snapshot of students' algebraic performance. Subsequently, inferential statistical analyses were applied to examine any notable variations in algebraic performance across the three groups. Specifically, a one-way Analysis of Variance (ANOVA) test was conducted to compare the mean scores of the experimental groups and the control group [46]. Furthermore, to understand students' responses regarding the use of Chat-GPT in linear algebra learning, the researchers distributed a questionnaire to assist in comprehensively analyzing students' perspectives on Chat-GPT.

In the meta-analysis process, 19 articles obtained through the PRISMA process were analyzed using the Comprehensive Meta-Analysis (CMA) application. CMA aids researchers in identifying effect sizes and provides graphical representations and data visualizations to enhance researchers' understanding of patterns and trends among research outcomes [47]. The combination of ANOVA and meta-analysis allows for a robust evaluation of the research hypotheses. ANOVA offers insights into the specific effects within the study, while meta-analysis integrates findings across studies to confirm the consistency and generalizability of the results. By utilizing both statistical analysis and meta-analysis, the research provides a well-rounded assessment of the interventions' effects, enhancing the reliability and depth of the study's conclusions.

In the qualitative research method, data triangulation was undertaken by combining multiple data sources to confirm and enrich the findings. In addition, interviews, observations and student learning test results were used to gain insight into students' understanding of technology and its integration into education. This method allows for a comprehensive exploration, ensuring a thorough examination of participants' perspectives on the intricate relationship between technology and education. The triangulation of data through interviews provides a multifaceted understanding, contributing to a nuanced and holistic portrayal of students' experiences and perceptions on technological integration in education. Meanwhile, the hermeneutic phenomenology provides a framework for a deep, qualitative exploration of Chat-GPT's capabilities in solving linear equations.

Table 2. Distinctions among three types of methods

Aspect	Quasi experimental design	Meta analysis review	Hermeneutic phenomenology
Sample	30 students	19 articles	5 students
Data collection	Post-test only	Scopus database, Publish or Perish and doctoral dissertation	Semi-structured interviews
Criteria	Participants included mathematics education students aged 20–23 who had completed the linear algebra course	Inclusion criteria: (a) Published between 2013–2024; (b) Written in English	Participants were a part of experimental classes integrating Chat-GPT
Data Analysis	ANOVA	CMA	Triangulation

The qualitative research method employed in this study was particularly valuable in exploring aspects that cannot be captured through quantitative methods alone. While quantitative approaches may offer statistical data on measurable variables, qualitative research delves into the deeper, more subjective dimensions of participants' experiences. In this study, qualitative interviews were used to examine students' personal attitudes, beliefs, and nuanced understandings of technology's role in education—

dimensions that are often beyond the scope of numerical analysis. Table 2 provides the distinctions among the three types of methods employed in this research.

IV. Results

A. Statistical Analysis in Mathematical Performance among Students

This segment provides an overview of the learning outcomes achieved by three distinct groups, followed by a discussion of algebra learning materials, how students viewed Chat-GPT's role in the learning process and shaping mathematical concepts, as well as the incorporation of Chat-GPT into educational methodologies.

In the quantitative method, the researchers sought to identify statistically significant differences in mathematical performance among students who solely relied on Chat-GPT without guidance from an instructor, those who received instructions aided by Chat-GPT, and those who received conventional instructions without Chat-GPT's assistance. To achieve this goal, the researchers used one-way ANOVA with the following research hypothesis to examine the sum of squares, degrees of freedom (df), mean squares, and significance (Sig):

$$H_0 : \mu_1 = \mu_2 = \mu_3$$

H_1 : At least two of the means are different

Table 3. ANOVA analysis output

Source of Variations	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5856.150	2	2928.075	9.745	0.001
Within Groups	8112.817	27	300.475		
Total	13968.967	29			

Based on the findings presented in Table 3, it is evident that the p_{value} is 0.001 and less than $\alpha = 0.05$, leading to the rejection of the null hypothesis (H_0). The p_{value} of 0.001 indicates that the results are highly significant, and the differences in students' mathematical performance across the groups are unlikely to have occurred by chance. This statistical significance demonstrates that there is a measurable difference in performance among the three groups. The results imply that the method of instruction (whether using Chat-GPT, a combination of Chat-GPT and an instructor, or conventional methods) plays a significant role in influencing students' mathematical performance. However, further analysis is needed to pinpoint which specific groups differ and to what extent. Table 4 illustrates the descriptive statistics data using ANOVA.

From the results of statistical analysis using ANOVA in Table 4, there is a significant difference between experimental group 1, which only used Chat-GPT, and experimental group 2, which used Chat-GPT with an instructor. Using Chat-GPT without guidance proves to be less effective, as indicated by several key points. First, the mean score for experimental group 1 is 53.25, which is the lowest value when compared to the other groups, indicating a comparatively weaker overall performance. Second, the standard deviation is relatively high (22.97), which shows significant variability in the learning outcomes. Third, the score range is wide (60 points), highlighting the considerable differences in students' understanding of the learning materials. The results shows that Chat-GPT alone does not provide consistent support for students' mathematical performance.

Table 4. Descriptive statistics

Value	Group	Statistic	Std. Error
1.00	Mean	53.2500	8.12129
	Std. Deviation	22.97048	
	Minimum	20.00	
	Maximum	80.00	
	Range	60.00	
2.00	Mean	87.5833	2.26454
	Std. Deviation	7.84461	
	Minimum	70.00	
	Maximum	95.00	
	Range	25.00	
3.00	Mean	68.4000	6.44843
	Std. Deviation	20.39172	
	Minimum	20.00	
	Maximum	90.00	
	Range	70.00	

Using Chat-GPT with expert guidance proves to be significantly more effective, as evidenced by several key factors. First, the mean score for experimental group 2 is 87.58, the highest among all groups, clearly indicating a stronger overall performance compared to the others. Second, the relatively low standard deviation (7.84) points to minimal variability in learning outcomes, suggesting more consistent results across the group. Third, the narrow score range (25 points) reflects greater uniformity in students' comprehension. These results indicate that integrating Chat-GPT with instructors support not only enhances performance but also leads to more consistent learning outcomes among students.

In the control group, which used the conventional method, the mean value was 68.4, which is lower than the group using Chat-GPT and instructor guidance, but higher than the group using Chat-GPT alone. Moreover, the standard deviation of 20.39172 indicates that there is considerable variability in student performance. The mean score for this group suggests that traditional instruction method still yields solid results, but the performance is not as high or as consistent as the group using Chat-GPT with instructor guidance. However, the results showed that the group using conventional instructions performed better than the group using Chat-GPT alone, indicating that human interaction remains important in the learning process. In summary, using Chat-GPT with an instructor (experimental group 2) in linear equation learning resulted in higher mean scores than using Chat-GPT alone (experimental group 1) or conventional methods (control group).

As the null hypothesis was rejected, subsequent post-hoc tests were conducted to identify specific combinations of group means that show significant differences. Table 5 illustrates the post-hoc test results.

In this analysis, the Tukey's Honest Significant Difference (HSD) test was used as the post-hoc method to compare the group means. The test was chosen since it helped identify specific group pairs with significant differences after the one-way ANOVA showed that the overall means were not equal. The test is effective at controlling errors when making multiple comparisons between groups. The post-hoc tests

reveal significant differences between Experimental 1 and Experimental 2 ($p_{tukey} = 0.001 < \alpha = 0.05$) as well as Experimental 2 and Control ($p_{tukey} = 0.04 < \alpha = 0.05$). However, no significant difference was found between Experimental 1 and Control ($p_{tukey} = 0.175 > \alpha = 0.05$). Considering the variance in means, it is essential to conduct further investigation into the utilization of Chat-GPT as an instructional tool in mathematics education, especially when complemented by instructor guidance. To achieve this goal, the researchers used meta-analysis to determine the effect of Chat-GPT on mathematics learning.

Table 5. Multiple comparisons analysis

(I) Group	(J) Group	Mean Difference (I–J)	Sig.	Description
1.00	2.00	–34.33333	0.001	Significant
	3.00	–15.15000	0.175	Not Significant
2.00	1.00	34.33333	0.001	Significant
	3.00	19.18333	0.040	Significant
3.00	1.00	15.15000	0.175	Not Significant
	2.00	–19.18333	0.040	Significant

In the didactic tetrahedron perspective, students who received comprehensive instructions solely through Chat-GPT (student-content-technology triangle) have the lowest average learning outcomes compared to students who were taught through the collaboration between Chat-GPT and an expert educator (teacher-content-technology triangle) and students who were taught through conventional learning methods (teacher-student-content triangle). This finding emphasizes that technology should be viewed as a supporting tool in the learning process, not as a complete substitute for educators. By serving as facilitators, providers of context, and promoters of critical thinking, teachers can effectively complement the capabilities of Chat-GPT. The integration of technology should be wisely adjusted and guided by the needs of students as well as the ability of educators to facilitate effective learning.

To reinforce the findings from the one-way ANOVA results, a meta-analysis was conducted to aggregate and analyze data from multiple studies, providing a broader perspective on the effect and reliability of the intervention across different contexts. In the meta-analysis, the data were analyzed using the Comprehensive Meta-Analysis (CMA) software. The researchers employed the random effects model since the secondary data in this study encompassed a wide range of variations, including differences in types of technology used, educational levels, geographical locations, and class sizes. Meta-analysis consistently highlights a moderating variable, which pertains to specific elements within the study that are relevant to the research findings [48]. Hedges' formula was utilized in the analysis to assess the effect size of integrating technology on students' performance in algebra as follows:

$$Hedges's\ g = \frac{X_1 - X_2}{S_{Pooled}} \quad (2)$$

The Effect Size (ES) obtained can be categorized into five distinct groups, as described by Thalheimer and Cook [49] and depicted in Table 6.

Table 6. Categorization of effect size

Range of Effect Size (ES)	Interpretation
$-0{,}15 \leq \text{ES} < 0.15$	Ignored
$0{,}15 \leq \text{ES} < 0.40$	Low
$0.40 \leq \text{ES} < 0.75$	Medium
$0.75 \leq \text{ES} < 1.10$	High
$1.10 \leq \text{ES} < 1.45$	Very High
$\text{ES} \geq 1.45$	Very Good

This research initially explored the impact of technology on students' performance in algebra. Table 7 details Hedges's g, standard errors, confidence intervals, Z-values, and P-values across the studies reviewed in the meta-analysis.

Table 7. Statistics descriptive for each study

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	*p*-Value
Tyagi. S. K. (2018)	0.134	0.086	0.007	–0.034	0.302	1.558	0.119
Zahda. F. H. (2019)	0.508	0.251	0.063	0.016	1.000	2.024	0.043
Tong. D. H. *et al*. (2021)	1.081	0.230	0.053	0.630	1.533	4.693	0.000
Pihlap. S. (2021)	0.079	0.140	0.020	–0.195	0.353	0.565	0.572
Sebial. S. C. (2017)	0.496	0.283	0.080	–0.058	1.050	1.753	0.080
Gakbish John. G. (2021)	0.533	0.166	0.027	0.209	0.858	3.219	0.001
Overmyer. G. R. (2014)	0.150	0.139	0.019	–0.123	0.423	1.079	0.281
Akinoso. O. (2018)	1.516	0.290	0.084	0.947	2.084	5.226	0.000
Wanjiru. B. (2015)	0.602	0.195	0.038	0.219	0.985	3.081	0.002
Kissi. P. S. (2016)	1.400	0.224	0.050	0.961	1.830	6.247	0.000
Kumar. R. R. et al. (2017)	0.570	0.260	0.068	0.060	1.080	2.191	0.028
Sherawat. J. (2022)	0.385	0.200	0.040	–0.007	0.778	1.924	0.054
Khalil. M. (2017)	0.858	0.324	0.105	0.222	1.494	2.645	0.008
Kliziene. I. (2021)	0.425	0.151	0.023	0.129	0.720	2.813	0.005
Kliziene. I. Taujanskiene. G. (2021)	0.824	0.156	0.024	0.519	1.129	5.299	0.000
Zulnaidi. H. (2017)	0.526	0.109	0.012	0.312	0.741	4.814	0.000
Lin. Y. W. (2016)	0.356	0.270	0.073	–0.147	0.886	1.317	0.188
Liburd. K. K. D. & Jen. H. Y. (2021)	0.767	0.343	0.118	0.095	1.439	2.236	0.025
Hegedus. S. J. (2015)	0.349	0.085	0.007	0.183	0.515	4.124	0.000
Pooled	0.562	0.081	0.007	0.403	0.721	6.929	0.000
Prediction Interval	0.562			–0.074	1.198		

Table 7 indicates that the overall effect size falls within the range of 0.07 to 1.51, with a 95% confidence interval. The variability in effect sizes occurred because the secondary data in this study drew different conclusions on the influence of technology, particularly Chat-GPT on mathematics education. These differences indicate that the effectiveness of Chat-GPT

in educational settings is highly dependent on how the technology is integrated, the subject matter, the level of learning difficulty, and the specific needs of the students. This variability highlights the importance of considering contextual factors when using Chat-GPT in education to maximize its potential benefits. Consistent with previous findings, to fully harness the potential of Chat-GPT, teachers should not allow students to rely solely on the technology. Teachers' role as a validator is crucial in verifying the accuracy, relevance, and depth of understanding of the content produced by Chat-GPT. However, discrepancies in effect sizes related to technology suggest variations in how technological interventions influence students' mathematical achievements. Table 8 provides a comprehensive analysis of the study's findings, employing different estimation techniques.

Table 8 illustrates the diverse range of effect sizes. Accordingly, the meta-analysis employed the random-effects model, whose effect size of 0.56 suggests that, in contrast to conventional learning, technology has a moderate effect on students' achievements in algebra. These findings indicate a significant and practical impact on learning outcomes. Specifically, they suggest that incorporating a technology intervention such as Chat-GPT may result in moderate improvements in student performance, such as a deeper understanding of concepts, enhanced mathematical skills, or improved test scores. In educational settings, this moderate effect can have substantial implications, particularly when applied to larger groups of students or over an extended period. While the effect is not exceptionally large, it is meaningful enough to demonstrate that technology can play a valuable role in improving learning outcomes. However, to achieve optimal results, the use of such technology may need to be complemented by additional teaching strategies and educator support.

Table 8. Description of meta-analysis results based on estimation method

Model	N	Hedges's g	95% Confidence Interval		Q
			Lower	Upper	
Fixed-effects	19	0.43	0.36	0.50	75.56
Random-effects	19	0.56	0.40	0.72	

To examine the potential existence of publication bias, it is advisable to analyze a funnel diagram. The funnel plot generated for this study is depicted in Fig. 7.

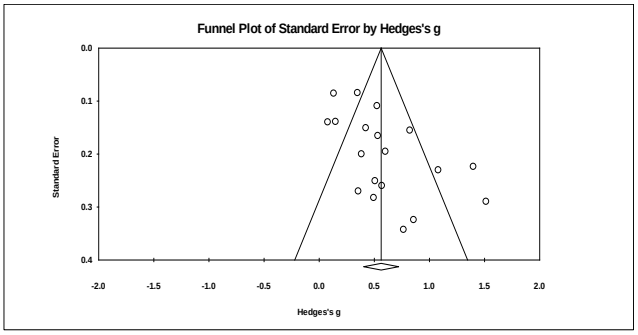


Fig. 7. Research funnel plot.

Based on the interpretation results of moderator variables using meta-analysis in Table 9, multimedia (Chat-GPT) has the most significant effect size among all types of technology analyzed, which is 1.15 (indicating a very high level). This means that the use of multimedia, especially Chat-GPT, has a very significant impact on improving student achievement in algebra.

Table 9. Interpretation of moderator variable outcomes in relation to type of technologies

Types of Technology	N	Effect Size	Test of Null (Two Tailed)		Heterogenity		
			Z-value	P-value	Q_b	Df (Q)	P-value
Animated learning	2	0.24	1.43	0.15	9.32	5	0.09
Computer	1	0.49	1.75	0.08			
E-learning	4	0.48	4.16	0.00			
GeoGebra	6	0.58	4.04	0.00			
Learning videos	3	0.29	2.51	0.01			
Multimedia (Chat-GPT)	3	1.15	3.76	0.00			

B. Students' Perception of Chat-GPT in Learning Process

Chat-GPT has a variety of benefits in mathematics learning, especially in algebra learning. It can function as a virtual assistant that helps students in understanding basic algebraic concepts, solving equations, and better understanding mathematical functions. With its ability to interactively process and answer algebra-related questions, Chat-GPT helps students practice problem-solving and critical thinking. In addition, it can also provide step-by-step explanations in solving problems, which is extremely useful for students with difficulty following classroom learning or those needing additional explanation outside of school hours. To further illustrate the effectiveness of Chat-GPT in supporting algebra learning, a series of interviews with students was conducted to gather insights into their experiences.

Researcher : *What is your experience in using Chat-GPT to learn algebra?*

Subject : *In my opinion, Chat-GPT is very helpful. Whenever I struggle with an algebra problem, I can ask ChatGPT right away, and it provides the answer quickly. It even explains the steps one by one, which helps me understand the topic better*

Researcher : *Do you see any positive effects from using Chat-GPT?*

Subject : *Yes, there is an obvious difference. In class, I sometimes cannot fully grasp the explanations, especially when the lessons move quickly. But with Chat-GPT, I can go over the material repeatedly until I truly understand it.*

Through easy interaction and flexible access, Chat-GPT helps make algebra learning more exciting and accessible. Fig. 8 depicts the viewpoint of 38 students in the third university on the incorporation of Chat-GPT in the learning process.

Based on Fig. 8, students responded positively to the integration of technology into education, specifically in how Chat-GPT provides guidance in solving mathematical problems. A total of 36.84% of students agreed, and 57.89% strongly agreed that the use of technology in mathematics learning helps students understand mathematical concepts better. Only 2.63% of students disagreed and strongly disagreed on conceptual understanding through the use of

Chat-GPT in learning. The strong agreement in the mathematical concept category demonstrates that students find Chat-GPT useful in grasping complex subjects such as mathematics. This supports the study's argument in quantitative results that Chat-GPT can be used as a supplementary tool to explain difficult concepts as well as providing personalized assistance and instant feedback that enhances comprehension. This is particularly useful in subjects such as mathematics, where step-by-step explanations and problem-solving guidance can significantly improve students' understanding. The student perceptions' data highlight the potential for Chat-GPT to be used in a tutoring capacity, assisting students who may struggle with particular concepts or need additional reinforcement outside the classroom. A total of 26.32% of students agreed, and 73.68% strongly agreed that integrating technology such as Chat-GPT into mathematics learning can increase their interest in learning and that Chat-GPT can enhance both cognitive and affective aspects of learning. Specifically, the students' increased interest in mathematics is a strong indicator that integrating AI into education can go beyond merely facilitating content delivery. It shows that such tools can positively influence students' motivation, which is a key driver of academic success. Furthermore, 47.36% of students agreed, and 50% strongly agreed that Chat-GPT can enhance the digital skills of educators and students. Only 2.63% of students disagreed that Chat-GPT can enhance their digital skills. The significant proportion of students who either agreed or strongly agreed that Chat-GPT enhances their digital skills indicates that Chat-GPT is an effective tool to foster technological proficiency. This observation aligns with one of the study's key hypotheses: that exposure to AI-based tools, such as Chat-GPT, can improve students' familiarity and competence with digital platforms. In an increasingly technology-driven world, these skills are not only desirable but also essential for success in both academic and professional environments.

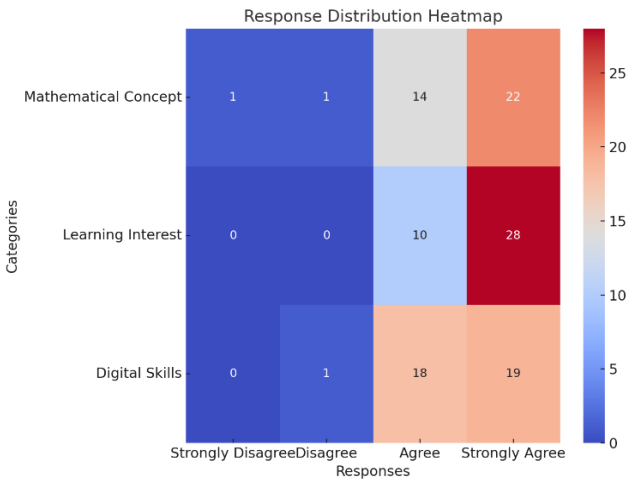


Fig. 8. Students' perception of Chat-GPT.

C. Chat-GPT's Role in Building Students' Conceptual Understanding

From a qualitative perspective, the researchers used hermeneutic phenomenology to observe students' opinions on the utilization of Chat-GPT for learning purposes and comprehending mathematical concepts. In general, the exploration of students' experiences using the hermeneutic phenomenology approach revealed that Chat-GPT helps students construct their conceptual knowledge, particularly in algebra learning. The qualitative data showed a consistent pattern of positive feedback regarding the tool's ability to help students understand mathematical concepts and increase their interest in learning. The vast majority of students (over 90%) agreed that Chat-GPT is an effective tool for supporting their algebra learning. However, a key pattern was observed. When the problems were relatively simple, Chat-GPT was able to solve them accurately. On the other hand, when the problems were more complex, Chat-GPT sometimes misinterpreted the answers. One unexpected finding was the comfort students felt using Chat-GPT, especially when they struggled in the classroom. Several students expressed relief at being able to ask questions freely without the pressure of being judged by their peers or teachers. One of the students stated, "*In class, if I don't immediately understand the concept, I feel embarrassed to ask. But with Chat-GPT, I can keep asking for explanations until I fully understand without feeling awkward*," which justifies the finding that Chat-GPT provides a pressure-free and non-judgmental learning environment. The interviews concentrated on inquiries regarding participants' encounters with Chat-GPT in linear algebra learning, their views on the tool's effectiveness, and the influence of Chat-GPT usage on their comprehension of algebraic concepts.

The thematic analysis of the interviews uncovered significant findings. In general, the students had prior knowledge of Chat-GPT before the research was conducted.

Researcher : *Can you describe how Chat-GPT helped you with linear algebra problems?*

Subject : *One of the more challenging problems I faced was solving a system of linear equations with two variables. Initially, I tried to solve the system using the elimination method, but I made a mistake in my calculations. Chat-GPT immediately flagged the error and explained what went wrong. Apparently, I had incorrectly added the equations instead of subtracting them to eliminate one of the variables.*

Researcher : *Did the feedback also help with understanding other aspects of the problem?*

Subject : *Yes, it was very helpful in understanding how to apply the elimination method properly. Chat-GPT not only corrected my mistake but also explained the rationale behind each step, such as why it's important to align coefficients when eliminating variables. This deeper understanding made it easier to apply the same method to other similar problems.*

Chat-GPT has the ability to construct students' conceptual understanding of linear algebra in various ways. Below is an example of an interview in which a student shared their

experience using Chat-GPT to solve a system of linear equations.

Researcher : *Can you tell me about your experience of using Chat-GPT to solve a system of linear equations?*

Subject : *When I was tasked with solving the system of equations, I started by inputting the equations into Chat-GPT. They were*

$$x + 5y - z = 12$$
$$3x + 4y + 6z = 23$$
$$2x - 3y + 2z = 2$$

Chat-GPT suggested that I must eliminate the variable z from one of the equations, and it helped me express z in terms of x and y using the first equation.

Researcher : *Did that make it easier for you to solve the problem?*

Subject : *Yes. By rewriting z as $x + 5y - 12$, I found it much simpler to substitute that into the other equations. It was much clearer than trying to eliminate y or x first.*

Researcher : *What did you learn from this substitution process?*

Subject : *I learned that substituting variables can really simplify things. Chat-GPT helped me see how all the variables are connected. After the substitution, I ended up with two new equations that only involved x and y, which made it easier to work with.*

First, Chat-GPT provides in-depth and detailed explanations of fundamental concepts, enabling students to grasp the theory behind the learning materials. Chat-GPT can also explain concepts from different perspectives, offering analogies and diverse examples that help students relate the learning materials to real-world situations or their existing knowledge. Second, Chat-GPT offers immediate feedback when students work on linear algebra problems. This feedback helps students recognize their mistakes, understand the correct problem-solving process, and reinforce their comprehension of more complex concepts. The features that students found most helpful for building their conceptual understanding were step-by-step guidance, immediate feedback, accessibility, and simplified language. These features allow students to reinforce their knowledge and gain confidence in mastering linear algebra concepts.

D. Chat-GPT's Hit-and-Miss Accuracy

While Chat-GPT offers various advantages, its disadvantages should be emphasized. A key disadvantage is that excessive dependence on this technology may diminish students' ability to think critically and solve problems independently. This study highlighted issues related to the poorly supervised use of Chat-GPT leading to a situation where students are more likely to look for quick answers rather than genuinely understanding the thought processes and in-depth mathematical concepts.

Furthermore, while Chat-GPT is able to provide quick and efficient answers, they are not consistently 100% accurate or relevant to the context of the questions, requiring further validation and review by teachers. This shows the importance of teachers' role as the mediator and supervisor in the use of this technology in education.

Researcher : *Based on your experience of using Chat-GPT, how does it fit into education?*

Subject : *In solving problems, especially math problems, some steps it produces need to be in accordance with the correct procedures, and there are several errors in the calculations.*

Researcher : *In your opinion, are there more positive impacts or negative impacts of using Chat-GPT?*

Subject : *Chat-GPT may give clear directions and steps in solving math problems. However, users need a precision feature to correct the errors in the answers provided. I do not think it is worth it to solve math problems with the help of Chat-GPT.*

Researcher : *Why is it not suitable for solving math problems using Chat-GPT? Do you have any personal experience with Chat-GPT's errors?*

Subject : *Yesterday, I found calculation errors in the steps for solving algebraic problems using elementary row operations. The definitions provided by Chat-GPT were also not correct, and Chat-GPT is not consistent in presenting definitions. For example, in the first question, I searched for the definition of an equation, and was provided with an answer. When I searched for the definition of an equation with the same prompt, the result was different.*

Based on the interviews, the use of Chat-GPT in an educational context, especially in solving mathematics problems, has a positive and negative impacts. Chat-GPT can solve problems accurately depending on the prompt and the complexity of the solution required. For example, if the following system of equations is inputted:

$$x + 5y - z = 12$$
$$3x + 4y + 6z = 23$$
$$2x - 3y + 2z = 2$$

and ChatGPT is asked to "determine the values of x, y, and z for the given system of linear equations," it provides the correct solution with the appropriate steps, yielding $x = 3$, $y = 2$, and $z = 1$. In this instance, the prompt is clear and the problem is relatively straightforward, with only substitution and elimination methods needed.

On the other hand, if the same system of equations is used but Chat-GPT is prompted to "solve using the elementary row operations method," it might return incorrect final values for x, y and z. This is due to the increased complexity of solving the system using the elementary row operations method. As a result, it might produce the following the outcome: $x = 41/55$,

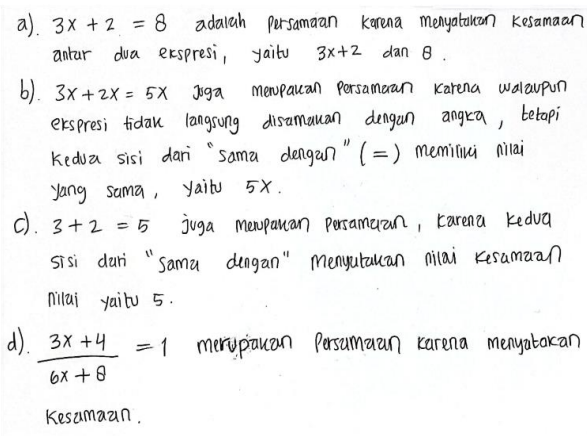
y = 55/74 and z = 5/1. This discrepancy highlights the fact that solving systems of equations using different methods and prompts may present varying levels of difficulty for an AI-based tool, leading to potential errors, especially in more complex methods such as elementary row operations. The quality and clarity of prompts significantly affect the accuracy of AI responses. In educational settings, this emphasizes the need for teachers and students to formulate precise questions or instructions when using AI tools. This skill could become increasingly vital as AI becomes more integrated into learning environments. In summary, Chat-GPT may provide clear directions and steps in working through problems, miscalculations, missteps, but inconsistencies in explanations may cause users to spend more time correcting mistakes and searching for the correct answers.

Based on the analysis, Chat-GPT is conceptually effective in guiding students in solving problems. However, consistent errors occur during the computational operations, such as addition, subtraction, multiplication, and division. These mistakes tend to repeat if users do not intervene by pointing out the error to Chat-GPT. Once users identify and highlight the specific mistake, Chat-GPT reprocesses the information, and the correct answer is typically provided upon the second attempt.

The use of Chat-GPT to solve mathematical problems is constrained by the requirement for clearer definitions and the inconsistency in locating such definitions. This can be seen from the subject's personal experience of finding calculation errors and incorrect explanations in the steps of solving algebraic problems using the elementary row operations. In addition, the use of Chat-GPT in searching for definitions could have been more consistent, with different results despite using the same prompt. Fig. 9 shows the subject's errors due to the use of Chat-GPT.

Based on the analysis using Chat-GPT, an equation is defined as "a mathematical statement that expresses the similarity between two expressions or values, usually using the sign (=)." To understand the definition of an equation, the researchers used a phenomenological method to compare the definitions of equations found in mathematics textbooks from five different curricula that have been implemented in Indonesia as presented in Table 10.

Students original answer


a). 3x + 2 = 8 adalah persamaan karena menyatakan kesamaan antar dua ekspresi, yaitu 3x+2 dan 8.
b). 3x + 2x = 5x juga merupakan persamaan karena walaupun ekspresi tidak langsung disamakan dengan angka, tetapi kedua sisi dari "sama dengan" (=) memiliki nilai yang sama, yaitu 5x.
c). 3 + 2 = 5 juga merupakan persamaan, karena kedua sisi dari "sama dengan" menyatakan nilai kesamaan nilai yaitu 5.
d). $\frac{3x+4}{6x+8}$ = 1 merupakan persamaan karena menyatakan kesamaan.

Translation

a). 3x+2=8 is an equation because it express quality between two expressions, namely 3x+2 and 8

b). 3x+2x=5x is also an equation because even though the expressions are not directly equated with a number, both sides of the "equals" (=) sign have the same value, which is 5x

c). 3+2=5 is also an equation because both sides of the 'equal' signs indicate the equality of the value, which is 5

d). 3x+4/6x+8=1 is indeed an equation because it expresses equality between two expressions.

Fig. 9. Errors due to the use of Chat-GPT.

Table 10. Definition of equation from various curricula in Indonesia

Curriculum	Book Title	Author(s)	Definition
Kurikulum Merdeka	*Matematika untuk Sekolah Menengah Pertama Kelas VII*	Gakko Tosho Team	A mathematical sentence that uses the equal sign to express the relationship between two quantities is called an equation.
Kurikulum 2013	*Matematika untuk SMP/MTs kelas VII Semester 1*	Abdur Rahman As'ari, Mohammad Tohir, Erik Valentino, Zainul Imron, and Ibnu Taufiq.	An equation is an open sentence that contains the equal sign (=)
Kurikulum Tingkat Satuan Pendidikan (KTSP)	*Matematika untuk SMP kelas VII*	Sukino, Wilson Simangunsong	An equation is an open sentence that includes the equal sign (=).
Kurikulum Berbasis Kompetensi (KBK)	*Matematika untuk SMP kelas VII Semester 1*	M. Cholik A, Sugijono, Subroto	An open sentence that uses the equal sign (=) is called an equation.
Kurikulum 1994	*Matematika untuk Kelas 1 SLTP*	Sunardi, Haryanta	An open sentence that indicates the "equal to" relationship (written as "=") is called an equation.

Based on Table 10, it is evident that the definition of an equation provided by Chat-GPT is similar to the definition found in the *Kurikulum Merdeka* textbook. However, Chat-GPT does not incorporate definitions from previous curricula because Chat-GPT processes information based on the most current knowledge available. Nevertheless, a deeper analysis reveals that all definitions of equations in textbooks other than *Kurikulum Merdeka* describe an equation as an "open sentence". The term "open sentence" is not included in Chat-GPT's definition. This term is crucial for differentiating between an equation and an identity. The absence of the term "open sentence" could lead to difficulties for students in solving problems such as those shown in Fig. 9.

Students with weak academic knowledge tend to readily accept the definition of an equation presented by Chat-GPT. Accordingly, the incorrect definition leads to learning

obstacles to occur. According to the academic knowledge version, an equation is an open sentence that contains the equal sign. However, an open sentence is a statement whose truth value is unknown because the elements are still unknown.

If students follow the definition of an equation based on Chat-GPT's explanation, they may get confused in understanding and learning algebra. Based on Fig. 9, students can still answer the question (a) correctly because $3x + 2 = 8$ has an equal sign and expresses similarity between the two expressions. However, when students were asked question (b), "Is $3x + 2x = 5x$ an equation or not?" the subject instead answered that the statement was an equation because of the definition provided by Chat-GPT, which includes the equal sign (=), and both sides have the same value, which is $5x$. In problems (c) and (d), the subject also answered that $3+2 = 5$ and $\frac{3x+4}{6x+8} = 1$ are equations, respectively. In fact, statements (c) and (d) are not inequalities because they are closed sentences whose truth value is unquestionable.

Based on an in-depth analysis using Chat-GPT, there were calculation errors and steps that had to follow the correct procedures in solving math problems. Table 11 illustrates the errors provided by Chat-GPT.

Table 11. Incorrect answers provided by Chat-GPT

Chat-GPT 3.5	**Chat-GPT 4.0**
Determine the values of x, y, and z for the following system of three-variable linear equations using Gauss-Jordan method: $$2x - 3y + 4z = 11$$ $$8x - 7y + 14z = 51$$ $$4x - 6y + 7z = 18$$	
To solve the system of three-variable linear equations using the Gauss-Jordan elimination method, let us represent the augmented matrix for the system: $$\begin{bmatrix} 2 & -3 & 4 & 11 \\ 8 & -7 & 14 & 51 \\ 4 & -6 & 7 & 18 \end{bmatrix}$$ **Step 1:** Divide the first row by 2 to make the leading coefficient in the first row equal to 1 $$\begin{bmatrix} 1 & -\frac{3}{2} & 2 & \frac{11}{2} \\ 8 & -7 & 14 & 51 \\ 4 & -6 & 7 & 18 \end{bmatrix}$$ **Step 2:** Multiply the first row by -8 and add it to the second row, and multiply the first row by -4 and add it to the third row $$\begin{bmatrix} 1 & -\frac{3}{2} & 2 & \frac{11}{2} \\ 0 & 5 & -2 & 13 \\ 0 & 6 & -1 & -1 \end{bmatrix}$$ **Step 3:** Multiply the second row by $\frac{1}{5}$ to make the leading coefficient in the second row equal to 1 $$\begin{bmatrix} 1 & -\frac{3}{2} & 2 & \frac{11}{2} \\ 0 & 1 & -\frac{2}{5} & \frac{13}{5} \\ 0 & 6 & -1 & -1 \end{bmatrix}$$ **Step 4:** Multiply the second row by $\frac{3}{2}$ and add it to the first row, and multiply the second row by -6 and add it to the third row $$\begin{bmatrix} 1 & 0 & \frac{17}{5} & \frac{26}{5} \\ 0 & 1 & -\frac{2}{5} & \frac{13}{5} \\ 0 & 0 & \frac{19}{5} & -\frac{109}{5} \end{bmatrix}$$ **Step 5:** Multiply the third row by $\frac{19}{5}$ to make the leading coefficient in the third row equal to 1 $$\begin{bmatrix} 1 & 0 & \frac{17}{5} & \frac{26}{5} \\ 0 & 1 & -\frac{2}{5} & \frac{13}{5} \\ 0 & 0 & 1 & -\frac{109}{5} \end{bmatrix}$$ Now we can read off the solution: $$x = \frac{26}{5} - \frac{17}{5}z$$ $$y = \frac{13}{5} + \frac{2}{5}z$$ $$z = -\frac{109}{19}$$	To solve the system of equations using the Gauss-Jordan method, we perform the row operations to transform the coefficient matrix into reduced row-echelon form. Initial matrix: $$\begin{bmatrix} 2 & -3 & 4 & 11 \\ 8 & -7 & 14 & 51 \\ 4 & -6 & 7 & 18 \end{bmatrix}$$ **Step 1:** Use the row operations to make the elements in column 1 zero, except for the element in row 1. $$R2 = R2 - 4R1$$ $$R3 = R3 - 2R1$$ $$\begin{bmatrix} 2 & -3 & 4 & 11 \\ 0 & 5 & -2 & 7 \\ 0 & 0 & -1 & -4 \end{bmatrix}$$ **Step 2:** Normalize row 2. $$R2 = \frac{R2}{5}$$ $$\begin{bmatrix} 2 & -3 & 4 & 11 \\ 0 & 1 & -\frac{2}{5} & \frac{7}{5} \\ 0 & 0 & -1 & -4 \end{bmatrix}$$ **Step 3:** Use the row operations to make the elements in column 2 zero, except for the element in row 2. $$R1 = R1 + 3R2$$ $$R3 = R3 + R2$$ $$\begin{bmatrix} 2 & 0 & 2 & 26 \\ 0 & 1 & -\frac{2}{5} & \frac{7}{5} \\ 0 & 0 & 0 & 3 \end{bmatrix}$$ **Step 4:** Normalize row 1. $$R1 = \frac{R1}{2}$$ $$\begin{bmatrix} 1 & 0 & 1 & 13 \\ 0 & 1 & -\frac{2}{5} & \frac{7}{5} \\ 0 & 0 & 0 & 3 \end{bmatrix}$$ With the matrix in reduced row-echelon form, we determine the solutions to the system of equations: $$x = 13$$ $$y = \frac{7}{5}$$ $$z = 3$$

In Chat-GPT 3.5, the solution consists of 5 steps, which were arranged hierarchically and systematically to make it easier for students to solve the mathematics problems. However, there was an operational error that occurred in step 2, which caused the overall steps to also be incorrect. In step 2, ChatGPT provided instruction to multiply the first row by -8 and add it to the second row, and then multiply the first row by -4 and add it to the third row. Based on the operations carried out using Chat-GPT, the following results were obtained:

$$\begin{bmatrix} 1 & -\frac{3}{2} & 2 & \frac{11}{2} \\ 0 & 5 & -2 & 13 \\ 0 & 6 & -1 & -1 \end{bmatrix}$$

There were 3 operational errors made by Chat-GPT in step 2 highlighted in red color. First, Chat-GPT concluded that $(-8 \times \frac{11}{2}) - 51 = 13$. Second, Chat-GPT concluded that $(-4 \times (-\frac{3}{2})) - 6 = 6$. Third, Chat-GPT concluded that $(-4 \times \frac{11}{2}) - 18 = -1$. If calculated manually, the results would be:

$$\begin{bmatrix} 1 & -\frac{3}{2} & 2 & \frac{11}{2} \\ 0 & 5 & -2 & 7 \\ 0 & 0 & -1 & -4 \end{bmatrix}$$

Using Chat-GPT 4.0, the solution consists of four steps, which were also arranged hierarchically and systematically to make it easier for students to solve the problems. However, there was an operational error in step 3, which caused step 4 and the final result to be incorrect. In step 3, ChatGPT directed to use row operations to make the elements in column 2 zero, except for the element in row 2. Based on the operational outcomes using Chat-GPT, the following results were obtained:

$$\begin{bmatrix} 2 & 0 & 2 & 26 \\ 0 & 1 & -\frac{2}{5} & \frac{7}{5} \\ 0 & 0 & 0 & 3 \end{bmatrix}$$

There were four operational errors made by Chat-GPT in step 3 highlighted in red color. First, Chat-GPT concluded that $(3 \times (-\frac{2}{5})) + 4 = 2$. Second, Chat-GPT concluded that $(3 \times \frac{7}{5}) + 11 = 26$. Third, Chat-GPT concluded that $(-2 \times 4) + 7 = 0$. Fourth, Chat-GPT concluded that $(-2 \times 11) + 18 = 3$. If calculated manually, the results would be:

$$\begin{bmatrix} 2 & 0 & \frac{14}{5} & \frac{76}{5} \\ 0 & 1 & -\frac{2}{5} & \frac{7}{5} \\ 0 & 0 & -1 & -4 \end{bmatrix}$$

While Chat-GPT versions 3.5 and 4.0 provide explanations and guidance through problem-solving methodologies, their reliability in generating accurate numerical solutions needs to be further investigated. This discrepancy underscores the importance of human oversight and validation, particularly in mathematical problem-solving tasks where precision is paramount. The complexity of mathematical problems, potential biases in training data, and the need for domain-specific expertise underscore the significance of human supervision and validation in ensuring the accuracy and integrity of numerical outputs.

V. Discussion

Chat-GPT is an artificial intelligence tool designed to interact in text-based conversations. Its use is relatively simple. Users enter a specific question or request, and it provides the relevant answers. As a novel artificial intelligence technology, Chat-GPT's application in education has garnered attention and sparked controversy [32, 50]. This research primarily focused on the utilization of Chat-GPT in linear algebra learning.

Chat-GPT has the ability to accelerate processes, simplify complex tasks, and perform repetitive actions that may be difficult or impossible for humans to perform. Chat-GPT plays a crucial role in enhancing efficiency. For example, in a classroom setting with several students, answering the same questions repeatedly can be time-consuming for a teacher. However, with the aid of technology, the process can be streamlined. This allows teachers and students to use the extra time to further develop students' cognitive abilities. In the didactic tetrahedron, technology serves as an extension of human cognition, enabling faster and more efficient processes [51]. In addition, technology acts as a subordinate element, where the primary driver of thought is the human mind. In other words, technology is an extension of the human intellect, supporting and enhancing human capacities rather than replacing them [52]. According to the Zone of Proximal Development (ZPD) theory [53], learning activates various latent mental processes that are only operational when students engage in interaction. The development achieved through independent problem-solving is termed actual development, while the growth that occurs as a result of interaction with teachers, peers, or technology is referred to as potential development. When used effectively, Chat-GPT serves as a tool that bridges the gap between actual development and potential development. In this context, Chat-GPT functions as a scaffolding mechanism, supporting learners as they work through new or complex learning materials. Meanwhile, teachers remain essential in offering contextualized feedback and personalized guidance, ensuring that students' learning is deepened and directed effectively.

The use of Chat-GPT in education aligns with the Technological Pedagogical Content Knowledge (TPACK) framework, which emphasizes the integration of technology (T), pedagogy (P), and content knowledge (CK) as illustrated in Fig. 10.

Through the TPACK framework, Chat-GPT combines technology, teaching methods, and content knowledge smoothly. It allows personalized learning by adapting to students' individual needs and providing clear explanations [54]. However, for the integration of Chat-GPT within the TPACK framework to be fully effective, teachers need adequate training. They must develop both technological proficiency and pedagogical strategies to effectively

incorporate AI into their classrooms.

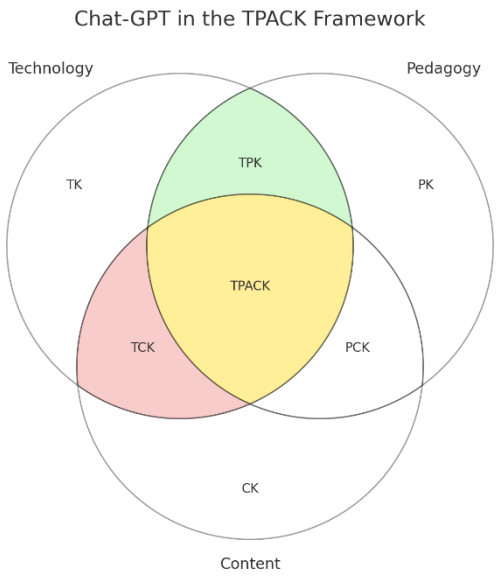


Fig. 10. TPACK framework.

Quantitatively, there exists a statistically significant difference in mathematical performance among students who solely rely on Chat-GPT without guidance from an instructor, those who receive instructions aided by Chat-GPT, and those who receive conventional instructions without Chat-GPT's assistance. Students who were taught through collaboration between Chat-GPT and an expert educator in the learning process had higher average learning outcomes compared to those who received guidance exclusively through Chat-GPT throughout the learning process, and those taught through conventional learning methods. The significant differences in learning outcomes show that combining technology such as Chat-GPT with support from instructors leads to better results than relying on either approach independently. This is in line with Fardian *et al.* [55], who stated that there is a positive relationship between the integration of technology in mathematics education and students' interest, collaboration, and motivation. The result highlights the need for education to keep up with technological advancements while also recognizing the important role teachers play in guiding students through the learning process. These findings are corroborated by the meta-analysis results, which indicate that multimedia (Chat-GPT) exhibits a very high effect size compared to other types of technology analyzed. Fig. 11 summarizes the advantages of Chat-GPT over other technologies based on the meta-analysis results. The six axes on the radar chart represent the learning features. Each colored polygon represents a different technology and its performance across the six learning features. The larger the area covered by the polygon, the stronger that technology performs in those areas.

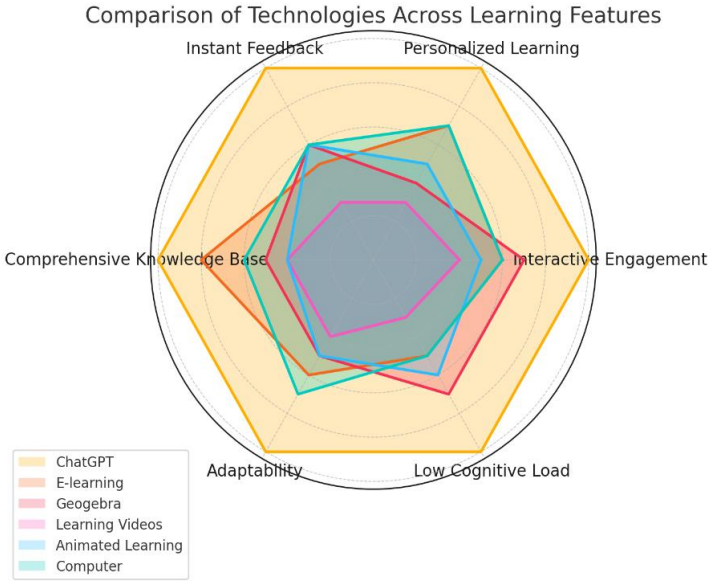


Fig. 11. Radar (spider) chart featuring comparison of different technologies.

Fig. 11 clearly demonstrates why Chat-GPT is the best tool when it comes to engaging and supporting learners across multiple dimensions of learning. Chat-GPT stands out by covering almost the entire radar for all six categories. The key advantage is its balance between interactivity, adaptability, and its ability to provide immediate feedback while managing cognitive load effectively. This makes Chat-GPT a more effective educational tool compared to static or less adaptive technologies. Other technologies such as e-learning, GeoGebra, and computers may be useful but have limitations in terms of interaction and flexibility. Tools such as learning videos and animated learning are more passive and less responsive to students' individual needs. This means that the use of multimedia, especially Chat-GPT, has a very significant impact on improving student achievement in algebra. This is in line with Gouia-Zarrad and Gunn [56], whose study results show that 65% of the students agreed that Chat-GPT helps generate new ideas or perspectives. These findings are consistent with recent research, such as Dowling and Lucey [57], which indicates that Chat-GPT can significantly aid in idea generation. Incorporating multimedia tools into mathematics learning creates a more engaging, visual, and interactive learning experience, aiding students in more effectively understanding and internalizing mathematical concepts [58–60].

However, one of the surprising results of this study is that

despite Chat-GPT's significant impact on students' learning outcomes, based on quantitative analysis, students who received comprehensive instructions solely through Chat-GPT have the lowest average learning outcomes compared to those who were taught through collaboration between Chat-GPT and an expert educator and students taught through conventional learning methods. The lack of human feedback and contextual guidance can indeed explain why Chat-GPT alone was less effective. The quality and clarity of the prompt significantly affect the accuracy of AI responses as Chat-GPT relies heavily on the input it receives to generate relevant and precise answers. When prompts are unclear, ambiguous, or lacking context, Chat-GPT may struggle to provide the most accurate or useful responses. As a consequence, teachers need training that focuses on understanding how to design effective prompts, critically evaluate AI responses, and integrate human feedback to complement Chat-GPT in learning. This is in line with Sherson and Vinchon [61] who stated that the comparative feedback could foster more refined evaluations in Chat-GPT interactions, highlighting the potential for better human-AI collaboration in optimizing prompts for clearer, more accurate responses. Steiss and Tate *et al.* [62] stated that feedback provided by humans on student writing tends to be of higher quality compared to feedback generated by Chat-GPT.

Forero and Herrera-Suárez [63] observed a decrease in student performance when Chat-GPT was used in the classroom, with concerns about its potential to reduce critical thinking. This emphasizes the significant role of instructors in delivering comprehensive and context-rich math instruction, with Chat-GPT serving as a supplementary tool in understanding concepts. This is further underscored by Zhu and Fan *et al*. [64] who explored the role of Chat-GPT in transforming students' learning experience. The study acknowledges the tool's benefits but also points out the need for careful use and human interaction. One of the critical roles of teachers is to justify the accuracy of the answers from Chat-GPT. Although Chat-GPT can provide reasonably accurate answers based on the data that have been studied, there is still a possibility that the answers are not entirely correct or need to fit the context of the problems or topics. Consequently, teachers' role as the evaluator of Chat-GPT answers is crucial, as they can provide the necessary expertise and knowledge to assess the accuracy and validity of the responses. This is particularly important in educational settings, where the teachers' guidance and validation can help ensure that students receive accurate information and learn effectively. Teachers also assist students in developing critical thinking skills. They not only provide the right or wrong answers, but also guide students to understand the thought process behind the answers. Thus, teachers can help students develop the ability to evaluate information, including the answers given by Chat-GPT critically. This is in line with Ibrahimi *et al.* [65], who stated that numerous educators consider it crucial and highly significant to utilize ICTs for facilitating communication and networking, contributing to continuous teacher training, simplifying complex concepts in teaching, fostering students' creativity and critical thinking, and locating as well as preparing instructional materials.

Qualitatively, students have a postive and negative perception on the utilization of Chat-GPT in facilitating learning and improving their understanding of mathematical concepts. Despite Chat-GPT's ability to provide quick and efficient responses, the answers it provides are only sometimes accurate or relevant to the question's context. This is in line with Getenet [66], who stated that although Chat-GPT primarily uses algebraic equations and formulas to arrive at accurate solutions, its use of different problem-solving approaches does not always lead to accurate results. Wardat *et al.* [67] observed that several factors can affect Chat-GPT's accuracy, including the specificity and comprehensiveness of the prompts, the complexity of the mathematical problems, the applicability and scope of Chat-GPT's training information, and the particular context and subject matter involved. Pavlova [68] stated that AI is still imperfect as it cannot provide examples and is prone to making mistakes.

Chat-GPT is an artificial intelligence language model designed to generate text that resembles human-written language. Its main goal is to generate outputs that are indistinguishable from what a person might compose, focusing on naturalness, coherence, and stylistic appropriateness. Unlike traditional programs that aim for factual accuracy, Chat-GPT's main goal is to be convincing rather than strictly accurate. This means that it can generate responses that sound plausible and natural, but not always be factually correct. The model achieves this by analyzing large quantities of textual data to grasp patterns of language use, allowing it to mimic human writing styles across various topics and contexts. However, users should be aware that while Chat-GPT excels in creating text that resembles human writing, it does not possess true understanding or knowledge. It synthesizes responses based on patterns found within the data it has been trained on and may sometimes generate inaccurate or misleading information [69]. Therefore, its outputs should be interpreted with caution, especially in contexts where factual accuracy is crucial. Silvestre *et al.* [70] and Shoufan [71] both found that students appreciate Chat-GPT's potential to enhance productivity, organization, and learning experience but are concerned about its limitations, such as answer reliability and ethical considerations. Ngo [72] further highlighted the benefits of Chat-GPT, including time-saving and personalized tutoring, but also identified barriers such as source reliability and citation accuracy. While Chat-GPT can simplify the writing process, it is essential to guarantee the accuracy and validity of the content [73, 74]. As observed, the reception of Chat-GPT often includes an element of hype. It is crucial to recognize that Chat-GPT lacks true intelligence, and that it rather functions as a technology akin to others. Consequently, it carries notable drawbacks, risks, and limitations [75].

Based on qualitative analysis, Chat-GPT can be used in the teaching of linear algebra with the assistance of an instructor as a validator in the learning process. Chat-GPT offers significant potential in helping students understand linear algebra, particularly in teaching fundamental concepts. As an AI-based tool, Chat-GPT can provide structured explanations on core topics such as linear equations, basic matrix operations, and systems of linear equations. The main advantage of Chat-GPT lies in its ability to deliver clear and detailed explanations and provide various relevant examples,

helping students build a solid understanding of basic learning materials. However, in the context of problem-solving, Chat-GPT tends to effectively handle only low-difficulty problems. When the problem is more complex, its tendency to provide incorrect answers increases. Therefore, it is recommended that Chat-GPT be used in education primarily for teaching fundamental concepts, while the role of explaining more abstract linear algebra concepts be entrusted to instructors. The combination of Chat-GPT usage and direct instructions by educators can create a more effective and comprehensive learning experience.

Given the potential risks of Chat-GPT usage in teaching, there is a recommended flowchart to guide students, teachers, or stakeholders to ensure its safe usage. The flowchart describes situations where Chat-GPT can be safely employed, alongside its limitations on reliability and the verification of provided information as illustrated in Fig. 12.

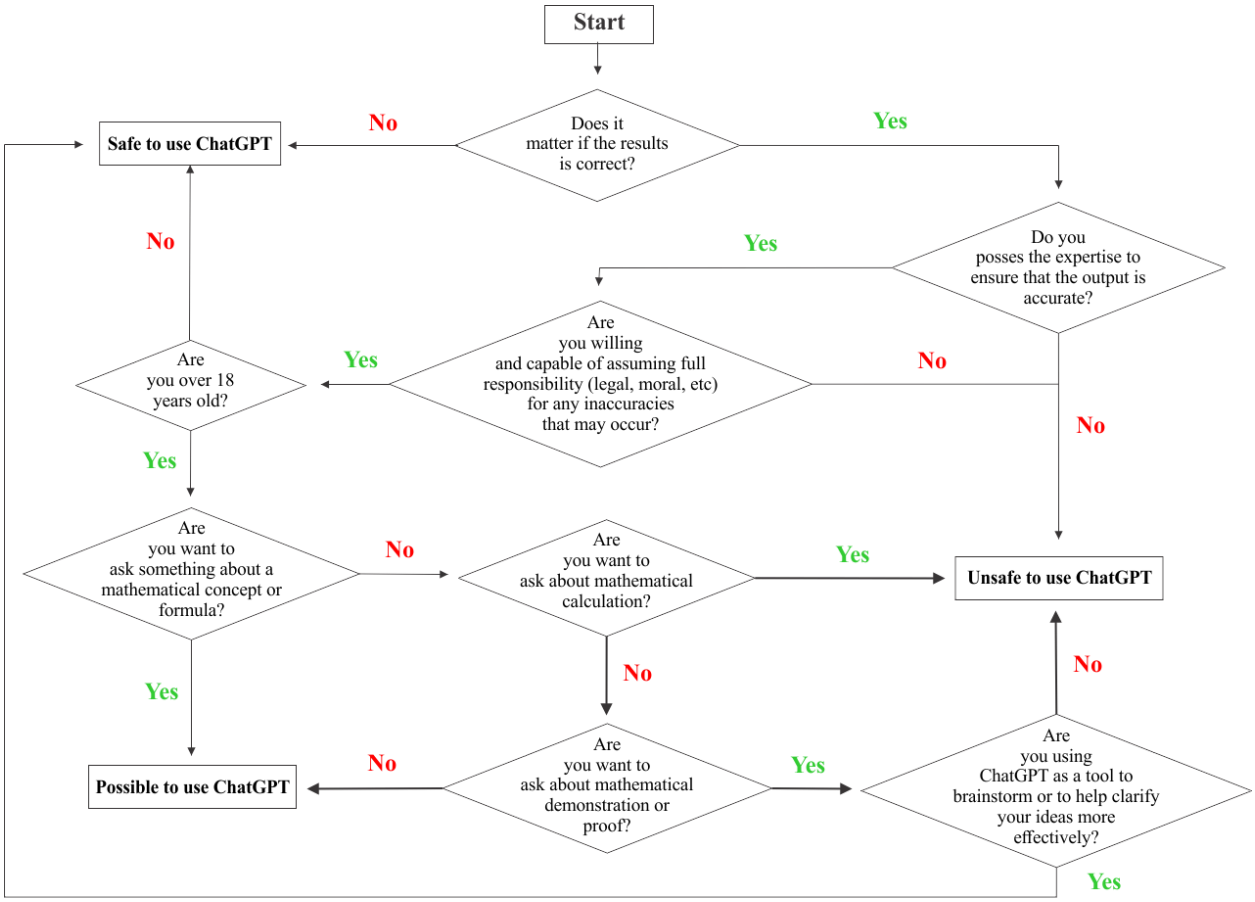


Fig. 12. Safe use of Chat-GPT flowchart.

In linear algebra learning, the use of Chat-GPT is more prudent and effective when applied in the context of providing guidance rather than solving problems. This is due to Chat-GPT's design and function as a language model that focuses on generating and explaining information, rather than performing complex mathematical calculations.

VI. Conclusion

The results of this research have important implications for learning process, particularly on the integration of technology such as Chat-GPT in linear algebra learning. Chat-GPT can provide step-by-step explanations for solving problems, which is extremely useful in helping students who have difficulty following learning in class or need additional explanation outside of school hours. Through easy interaction and flexible access, Chat-GPT helps make mathematics learning more engaging and accessible. However, while technology can be a handy resource in enriching the educational experience, the role of the educator as a facilitator, justifier, and guide cannot be replaced. The combination of technology and educator interaction will ensure that learning not only becomes more engaging and accessible but also more effective in developing students' understanding. Before implementing AI-driven language models such as Chat-GPT, it is crucial for teachers to prioritize establishing a solid foundation of mathematical understanding and abilities in students. This foundational understanding ensures that students can effectively verify the correctness of information provided by these tools. It is essential that students grasp fundamental mathematical concepts and approaches to problem-solving beforehand to maximize the benefits of using such advanced technological tools in their learning process.

This study follows a sequential exploratory design, in which the focus is on gathering quantitative data, followed by qualitative data collection to further explain and build upon the initial results. The research emphasizes a strong quantitative orientation, with quantitative data serving as the foundation for starting the research process. Qualitative data were then employed to add depth and context, offering insights into students' personal experiences and interpretations, thus clarifying the initial quantitative findings. In this study, the qualitative phase primarily builds on the already-established quantitative results, potentially limiting

the exploration of personal experiences. This approach might miss out on richer, more subjective insights that could emerge if qualitative data were given precedence. Therefore, future researchers are recommended to adopt an explanatory approach, moving from qualitative to quantitative data collection. The shift would allow for a deeper exploration of how students experience Chat-GPT, with qualitative insights guiding the subsequent quantitative analysis. In adopting the explanatory approach, future researchers can ensure that their study not only captures the "what" (i.e., measurable outcomes) but also the "why" and "how" behind those outcomes.

This study is limited by the use of Chat-GPT version 3.5 and was conducted on a small-scale sample of 30 participants, with an actual power of 80%. While this is sufficient to detect the expected effect, the small sample size may limit the generalizability of the findings. Therefore, future research is recommended to examine a larger sample size and higher actual power. By increasing the actual power, the study will have a greater ability to detect true effects and provide more confidence in the reliability of the findings. This would reduce the risk of errors in drawing conclusions and enhance the overall validity of the results. This research only focuses on the integration of Chat-GPT within the area of linear algebra learning. Since Chat-GPT is an artificial intelligence based on language programming, further research is needed to investigate the relationship between technology integration and non-science disciplines. In addition, this research only focuses on exploring artificial intelligence-based technology in solving calculation-based problems. Further research is recommended to explore programming-based technology that is specifically designed to solve mathematics-based problems such as MATrix LABoratory (MATLAB), Mathematica, or Maple in solving complex problems and how these tools complement or differ from AI language models such as Chat-GPT. This research also focuses on the integration of Chat-GPT in higher education. Future studies could also explore the use of Chat-GPT in lower-grade classrooms.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

DF: Writing—original draft, Conceptualization, Investigation, Resources, Visualization; DS: Writing—review and editing, Formal analysis, Methodology, Supervision, Validation; SP: Writing—original draft, Formal analysis, Methodology, Validation; AJ: Writing—review and editing, Methodology, Validation. All authors had approved the final version.

Funding

This research was funded by the Ministry of Education, Culture, Research, and Technology of Indonesia; and the Directorate of Research, Technology, and Community Service No. 082/E5/PG.02.00.PL/2024 through PMDSU (Master's to Doctoral Program for Outstanding Bachelor's Graduates) scheme, 2024.

Acknowledgment

We thank to Said Fachry Assagaf and Lussy Midani Rizki for their help in the data collection process.

References

[1] R. Raja and P. C. Nagasubramani, "Impact of modern technology in education," *Journal of Applied and Advanced Research*, vol. 3, no. 1, pp. 33–35, 2018.

[2] E. Van-Laar, A. J. Van-Deursen, J. A. Van-Dijk, and J. De-Haan, "The relation between 21st-century skills and digital skills: A systematic literature review," *Computers in Human Behavior*, vol. 72, pp. 577–588, 2017.

[3] A. Suherman, M. Komaro, and A. Ana, "E-book multimedia animation implementation on concept mastery and problem-solving skills of crystal structure subjects in engineering materials course," *Indonesian Journal of Science and Technology*, vol. 8, no. 2, pp. 259–280. 2023.

[4] A. L. Cloete, "Technology and education: Challenges and opportunities," *HTS: Theological Studies*, vol. 73, no. 3, pp. 1–7, 2017.

[5] M. Escueta, V. Quan, A. J. Nickow, and P. Oreopoulos, "Education technology: An evidence-based review," *NBER Working Paper*, no. 23744, 2017.

[6] N. Nurdyansyah, P. Rais, and Q. Aini, "The role of education technology in mathematic of third grade students in MI Ma'arif Pademonegoro Sukodono," *Madrosatuna: Journal of Islamic Elementary School*, vol. 1, no. 1, pp. 37–46, 2018.

[7] N. Selwyn, *Is Technology Good for Education?* John Wiley & Sons, 2016.

[8] M. T. Sanz, C. Melgarejo, and E. López-Iñesta, "Indicators of knowledge, usefulness, and use of ICT among primary schoolteachers," *JOTSE*, vol. 13, no. 3, pp. 917–935, 2023.

[9] J. K. Carroll, A. Moorhead, R. Bond, W. G. LeBlanc, R. J. Petrella, and K. Fiscella, "Who uses mobile phone health apps and does use matter? A secondary data analytics approach," *Journal of Medical Internet research*, vol. 19, no. 4, p. e125, 2017.

[10] F. R. Ben and M. Lahami, "Application of blockchain technology in healthcare: A comprehensive study," in *Proc. the 18th International Conference on Impact of Digital Technologies on Public Health in Developed and Developing Countries (ICOST 2020)*, Springer International Publishing, 2020, pp. 268–276.

[11] H. A. R. Afendi and S. F. A. Widodo, "The transformation of madrasah through the use of education technology," *International Journal of Teaching and Learning*, vol. 2, no. 5, pp.1338–1348, 2024.

[12] R. Annisa, S. M. Nadila, S. A. Salsabila, S. A. E. Putri, and H. Nurmajesti, "E-learning as an adaptation strategy in facing COVID-19 pandemic: A case study on the 2018 and 2019-generation students of post graduate Sociology Department, University of Indonesia," in *Proc. 6th International Conference on Social and Political Sciences (ICOSAPS 2020)*, Atlantis Press, 2020, pp. 40–44.

[13] D. Suryadi, "Philosophical foundations of didactical design research," Pusat Pengembangan DDR Indonesia, 2019. (in Indonesian)

[14] D. Dasari, A. Hendriyanto, S. Sahara, D. Suryadi, L. H. Muhaimin, T. Chao, and L. Fitriana, "Chat-GPT in didactical tetrahedron, does it make an exception? A case study in mathematics teaching and learning," *Frontiers in Education*, vol. 8, 1295413, 2024.

[15] M. Bosch, "Doing research within the anthropological theory of the didactic: The case of school algebra," in *Proc. the 12th International Congress on Mathematical Education*, Springer International Publishing, 2015, pp. 51–69.

[16] L. Herbert, *Digital Transformation: Build Your Organization's Future for the Innovation Age*, Bloomsbury Publishing, 2017.

[17] K. Ruthven, "The didactical tetrahedron as a heuristic for analysing the incorporation of digital technologies into classroom practice in support of investigative approaches to teaching mathematics," *ZDM-Mathematics Education*, vol. 44, pp. 627–640, 2012.

[18] J. Olive, K. Makar, V. Hoyos, L. K. Kor, O. Kosheleva, and R. Strässer, "Mathematical knowledge and practices resulting from access to digital technologies," in *Proc. the 17th ICMI, Study on Mathematics Education and Technology-Rethinking the Terrain*, 2010, pp. 133–177.

[19] D. Tall, "Using the computer as an environment for building and testing mathematical concepts: A tribute to richard skemp," *Honour of Richard Skemp*, pp. 21–36, 1986.

[20] R. Novita and T. Herman, "Digital technology in learning mathematical literacy, can it helpful?" *Journal of Physics: Conference Series*, vol. 1776, no. 1, 012027, 2021.

[21] M. Lugalia, S. Johnston-Wilder, and J. Goodall, "Using ICT and dialogic teaching: impact on mathematical resilience and attainment in algebra of a Kenyan school year group," *Edulearn15 Proceedings*, 2015.

[22] A. D. Putri, Y. Yerizon, A. Arnellis, and S. Suherman, "Development of realistic mathematics education-based teaching materials to increase

students' mathematical literacy ability," *AIP Conference Proceedings*, vol. 3024, no. 1, 2024.

[23] D. Fardian, D. Suryadi, and S. Prabawanto, "A praxeological analysis of linear equations in Indonesian mathematics textbooks: Focusing on systemic and epistemic aspect," *Journal on Mathematics Education*, vo. 16, no. 1, 2025. https://doi.org/10.22342/jme.v16i1.pp201-228

[24] S. Frieder, L. Pinchetti, R. R. Griffiths, T. Salvatori, T. Lukasiewicz, P. Petersen, and J. Berner, "Mathematical capabilities of Chat-GPT," *Advances in Neural Information Processing Systems*, vol. 36, 2024.

[25] V. Božić and I. Poola, "Chat GPT and education," Preprint, 2023. doi: 10.13140/RG.2.2.18837.40168

[26] A. R. Kirmani, "Artificial intelligence-enabled science poetry," *ACS Energy Letters*, vol. 8, no. 1, pp. 574–576, 2022.

[27] A. M. A. Ausat, B. Massang, M. Efendi, N. Nofirman, and Y. Riady, "Can Chat GPT replace the role of the teacher in the classroom: A fundamental analysis," *Journal on Education*, vol. 5, no. 4, pp. 16100–16106, 2023.

[28] F. Fauzi, L. Tuhuteru, F. Sampe, A. M. A. Ausat, and H. R. Hatta, "Analysing the role of Chat-GPT in improving student productivity in higher education," *Journal on Education*, vol. 5, no. 4, pp. 14886–14891, 2023.

[29] M. Turmuzi, I. G. P. Suharta, I. W. P. Astawa, and I. N. Suparta, "Perceptions of primary school teacher education students to the use of Chat-GPT to support learning in the digital era," *International Journal of Information and Education Technology*, vol. 14, no. 5, 2024.

[30] K. Fuchs and V. Aguilos, "Integrating artificial intelligence in higher education: Empirical insights from students about using Chat-GPT," *International Journal of Information and Education Technology*, vol. 13, no. 9, pp. 1365–1371, 2023.

[31] S. K. Cho, "Letter re: Reply to letter to editor on Chat-GPT and its role in the decision-making for the diagnosis and treatment of lumbar spinal stenosis: A comparative analysis and narrative review," *Global Spine Journal*, 2023.

[32] H. Yu, "Reflection on whether Chat GPT should be banned by academia from the perspective of education and teaching," *Frontiers in Psychology*, vol. 14, 1181712, 2023.

[33] T. Son, "Exploring the possibility of using Chat-GPT in mathematics education: Focusing on student product and pre-service teachers' discourse related to fraction problems," *Education of Primary School Mathematics*, vol. 26, no. 2, pp. 99–113. 2023.

[34] P. H. Li, H. Y. Lee, Y. P. Cheng, A. I. Starčič, and Y. M. Huang, "Solving the self-regulated learning problem: Exploring the performance of Chat-GPT in mathematics," in *Proc. International Conference on Innovative Technologies and Learning*, Cham: Springer Nature Switzerland, 2023, pp. 77–86.

[35] S. G. Lee, D. Park, J. Y. Lee, D. S. Lim, and J. H. Lee, "Use of Chat-GPT in college mathematics education," *Mathematical Education*, vol. 63, no. 2, pp. 123–138, 2024.

[36] F. O. Egara and M. Mosimege, "Exploring the integration of artificial intelligence-based Chat-GPT into mathematics instruction: Perceptions challenges, and implications for educators," *Education Sciences*, vol. 14, no. 7, 742, 2024.

[37] N. Khan, Z. Khan, A. Koubaa, M. K. Khan, and R. B. Salleh, Global insights and the impact of generative AI-Chat-GPT on multidisciplinary: A systematic review and bibliometric analysis," *Connection Science*, vol. 36, no. 1, 2353630, 2024

[38] Y. Wardat, M. A. Tashtoush, R. Al-Ali, and A. M. Jarrah, "Chat-GPT: A revolutionary tool for teaching and learning mathematics," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 19, no. 7, em2286, 2023.

[39] J. P. Remoto, "Chat-GPT and other AIs: Personal relief and limitations among mathematics-oriented learners," *Environment and Social Psychology*, vol. 9, no. 1, 2023.

[40] Z. A. Pardos and S. Bhandari, "Chat-GPT-generated help produces learning gains equivalent to human tutor-authored help on mathematics skills," *Plos One*, vol. 19, no. 5, e0304013, 2024.

[41] R. W. McGee, "What will the United States look like in 2050?" *A Chat-GPT Short Story*, 2023.

[42] Y. Qawqzeh, "Exploring the influence of student interaction with Chat-GPT on critical thinking, problem solving, and creativity," *International Journal of Information and Education Technology*, vol. 14, no. 4, 2024.

[43] A. Giorgi, "A phenomenological perspective on certain qualitative research methods," *Journal of Phenomenological Psychology*, vol. 25, no. 2, pp. 190–220, 1994.

[44] J. W. Creswell, *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*, Pearsons, 2015.

[45] Sugiyono, "Quantitative and qualitative research methods," *Alfabeta*, 2018. (in Indonesian)

[46] J. Gillard, "One-way analysis of variance (ANOVA)," *A First Course in Statistical Inference*, pp. 91–101, 2020.

[47] E. Kulinskaya and J. Koricheva, "Use of quality control charts for detection of outliers and temporal trends in cumulative meta-analysis," *Research Synthesis Methods*, vol. 1, no. 3–4, pp. 297–307, 2010.

[48] D. Fardian and D. Dasari, "The effects of problem-based learning on mathematical proficiency: A combined bibliometric analysis and meta-analysis review," *Journal of Didactic Studies*, vol. 1, no. 2, pp. 99–113, 2023.

[49] W. Thalheimer and S. Cook, "How to calculate effect sizes from published research: A simplified methodology," *Work-Learning Research*, vol. 1, no. 9, pp. 1–9, 2002.

[50] M. Sullivan, A. Kelly, and P. McLaughlan, "Chat-GPT in higher education: Considerations for academic integrity and student learning," *Journal of Applied Learning & Teaching*, vol. 6, no. 1, pp. 1–10, 2023.

[51] A. Hendriyanto, D. Suryadi, S. Sahara, D. Fardian, I. Pauji, and L. H. Muhaimin, "From tools to thought partners: Optimizing technology as extended cognition for innovative didactic design," *AIP Conference Proceedings*, vol. 3220, no. 1, AIP Publishing, 2024

[52] M. A. O. Carrillo and D. C. C. Gonzalez, "Technology as an extension of personal capabilities. reflections for organizational development," *Technium. Soc. Sci. J.*, vol. 6, no. 41, 2020.

[53] L. Vygotsky, *Thought and Language*, Cambridge, MA: M.I.T. Press, 1962.

[54] P. Klayklung, P. Chocksathaporn, P. Limna, T. Kraiwanit, and K. Jangjarat, "Revolutionizing education with Chat-GPT: Enhancing learning through conversational AI," *Universal Journal of Educational Research*, vol. 2, no. 3, pp. 217–225, 2023.

[55] D. Fardian, T. Herman, D. Suryadi, and S. Prabawanto, "Gamifying Mathematics: A hermeneutic phenomenological study focused on role-playing games in linear equations," *PYTHAGORAS Jurnal Pendidikan Matematika*, vol. 19, no. 1, 2024.

[56] R. Gouia-Zarrad and C. Gunn, "Enhancing students' learning experience in mathematics class through Chat-GPT," *International Electronic Journal of Mathematics Education*, vol. 19, no. 3, 2024.

[57] M. Dowling and B. Lucey, "Chat-GPT for (finance) research: The Bananarama conjecture," *Finance Research Letters*, vol. 53, 2023.

[58] D. Fardian, D. Suryadi, S. Prabawanto, and S. Hayuningrat, "Research trends on early algebra in the middle school: A combined bibliometric and meta-analysis review," *Jurnal Elemen*, vol. 10, no. 2, pp. 410–440, 2024.

[59] A. D. Putri, D. Juandi, A. Jupri, and S. B. Muchsin, "Mastering the TPACK framework: Innovative approaches by mathematics teachers," *Jurnal Elemen*, vol. 10, no. 3, pp. 582–594. 2024.

[60] A. D. Putri, D. Juandi, and T. Turmudi, "Realistic mathematics education and mathematical literacy: A meta-analysis conducted on studies in Indonesia," *Journal of Education and Learning (EduLearn)*, vol. 18, no. 4, pp. 1468–1476, 2024.

[61] J. Sherson and F. Vinchon, "Facilitating human feedback for GenAI prompt optimization," arXiv preprint, arXiv:2404.15304, 2024.

[62] J. Steiss, T. Tate, S. Graham, J. Cruz, M. Hebert, J. Wang, Y. Moon, W. Tseng, M. Warschauer, and C. B. Olson, "Comparing the quality of human and Chat-GPT feedback of students' writing," *Learning and Instruction*, vol. 91, 101894, 2024.

[63] M. G. Forero and H. J. Herrera-Suárez, "Chat-GPT in the classroom: Boon or bane for physics students' academic performance?" arXiv preprint, arXiv:2312.02422, 2023.

[64] G. Zhu, X. Fan, C. Hou, T. Zhong, P. Seow, A. C. Shen-Hsing, and T. L. Poh, "Embrace opportunities and face challenges: Using Chat-GPT in undergraduate Students' collaborative interdisciplinary learning," arXiv preprint, arXiv:2305.18616, 2023

[65] E. Ibrahimi, F. Miri, and I. Koçiaj, "An assessment of the integration of ICTs into teaching processes by science teachers: The case of Albania," *JOTSE*, vol. 14, no. 2, pp. 405–417, 2024.

[66] S. Getenet, "Pre-service teachers and Chat-GPT in multistrategy problem-solving: Implications for mathematics teaching in primary schools," *International Electronic Journal of Mathematics Education*, vol. 19, no. 1, 2024.

[67] Y. Wardat, M. A. Tashtoush, R. AlAli, and A. M. Jarrah, "Chat-GPT: A revolutionary tool for teaching and learning mathematics," *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 19, no. 7, 2023.

[68] N. H. Pavlova, "Flipped dialogic learning method with Chat-GPT: A case study," *International Electronic Journal of Mathematics Education*, vol. 19, no. 1, 2024.

[69] M. T. Hicks, J. Humphries, and J. Slater, "Chat-GPT is bullshit, *Ethics and Information Technology*, vol. 26, no. 2, 38, 2024.

[70] A. S. S. Silvestre, E. L. de Moura Amaral, M. E. Holanda, and E. D. Canedo, "Students' perception about Chat-GPT's impact on their

Academic Education," *in Proc. Anais do XXXIV Simpósio Brasileiro de Informática na Educação*, 2023, pp. 1260–1270.

[71] A. Shoufan, "Exploring students' perceptions of Chat-GPT: Thematic analysis and follow-up survey," *IEEE Access*, 2023.

[72] T. T. A. Ngo, "The perception by university students of the use of Chat-GPT in education," *International Journal of Emerging Technologies in Learning*, vol. 18, no. 17, 4, 2023.

[73] K. Kassem and F. Michahelles, "Et Machina: Exploring the use of conversational agents such as Chat-GPT in scientific writing," *Placeholder Parent Metadata Value*, vol. 3502, 2023.

[74] T. S. C. Ocampo, T. P. Silva, C. Alencar-Palha, F. Haiter-Neto, and M. L. Oliveira, "Chat-GPT and scientific writing: A reflection on the ethical boundaries" *Imaging Science in Dentistry*, vol. 53, no. 2, 175, 2023.

[75] F. Allwein, "Chat-GPT-A critical view," *IU Discussion Papers-IT & Engineering*, 2024.

Copyright © 2025 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).