

Use of ChatGPT as a supplemental learning tool in mathematics

Maria Rhoda Damos Sosas^{1*} , Arcelli Faith Getalla Fat¹ , Jody May Minao Dangculos¹ ,
Harvey Rex Pitogo Anoba¹ , Charlene Go Remiscal¹ , Judith M. Aleguen¹ 

¹Cebu Technological University–Argao Campus, Cebu, PHILIPPINES

*Corresponding Author: sosamaria7@gmail.com

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ABSTRACT

As artificial intelligence (AI) technologies are increasingly emphasized to supplement individual pursuits of knowledge in today's learner-centric educational paradigm, the development of chat generative pre-trained transformer (ChatGPT) by OpenAI has marked a significant milestone. This AI system, designed to generate human-like dialogue and written responses, presents an exciting application in mathematics education. As accumulating research focuses on the experimentation and content analysis of ChatGPT's responses, this study explored the perspectives and experiences of secondary mathematics pre-service teachers with the tool in their mathematics learning. Employing a mixed-method approach, the study combined quantitative surveys with 91 respondents and qualitative interviews with 20 participants, to evaluate their perceptions of ChatGPT's ease of use, relative advantage, compatibility, and intention to use it, grounded in the diffusion of innovation theory, connectivism learning theory, technology acceptance model, and community of inquiry framework. Based on statistical and thematic analysis, the pre-service teachers exhibited a positive perception of using ChatGPT as a supplemental learning tool in mathematics, noting it as very easy to use, beneficial for efficient learning and task completion, and cognitive development, and compatible with learning citing its adaptability to learners' needs and demands in education. However, challenges and issues such as occasional inaccuracies, functional limitations, the risk of over-reliance, and academic integrity were noted, emphasizing that ChatGPT is a valuable supplementary tool in mathematics education provided that it is used responsibly and in balance with other learning resources.

Keywords: ChatGPT, mathematics learning, pre-service teachers, supplemental learning tool

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INTRODUCTION

Educational demands require innovation and creativity. The development of artificial intelligence (AI) has fundamentally influenced not only people's lifestyles but also the teaching and learning processes. Not surprisingly, the chat generative pre-trained transformer (ChatGPT) emerged as the widely adopted AI tool in education. Recent studies indicate that ChatGPT has the potential to enhance teaching and learning (Javaid et al., 2023; Wu & Yu, 2023) due to its adaptive capabilities (Baidoo-Anu & Ansah, 2023) and ability to personalize learning (Ahmad et al., 2023; Moore et al., 2023). However, concerns persist among stakeholders regarding the accuracy of its content, the credibility of its sources (Ruiz et al., 2023; Zhu et al., 2023), the validity of its responses (Khlaif et al., 2023), and potential misuse by students (Baidoo-Anu & Ansah, 2023; Kooli, 2023; Rahman et al., 2023; Sušnjak, 2022; Zhai, 2022). Given its primarily textual nature, the application of ChatGPT in mathematics education and its potential benefits for students' learning outcomes and engagement warrant substantial exploration.

Accumulating research has explored ChatGPT's mathematical capabilities by investigating user experiences and analyzing its responses. Studies have found that ChatGPT is the most effective mathematical assistant for querying facts (Dao & Le, 2023; Frieder et al., 2023). However, its effectiveness decreases as the difficulty level of mathematical problems increases, showing optimal performance in knowledge-level questions but faltering at higher difficulty levels (Cheng & Yu, 2023; Dao & Le, 2023). User experiences highlight issues such as ChatGPT's lack of deep understanding in various mathematical subfields, including arithmetic, geometry, and calculus (Dao & Le, 2023; Wardat et al., 2023). Nonetheless, ChatGPT's enhanced mathematical capabilities can contribute to educational success by supplementing traditional classroom settings and enriching the interactive and emotional support in the student-teacher dynamic (An et al., 2023; Wardat et al., 2023). Ruiz et al. (2023) have shown that students have quickly adopted ChatGPT, exhibiting high confidence in its responses (3.4/4.0) and general usage in the learning process (3.61/4.0), alongside a positive overall evaluation.

In the Philippines, Estrellado and Miranda (2023) posited that incorporating AI in education provides numerous opportunities to

improve the learning journey. Melchor et al. (2023) argued that integrating AI into mathematics education offers personalized guidance, fosters critical thinking skills, and prepares generation alpha learners for the challenges of the digital era. Despite significant research on AI technologies in education in the Philippines, peer-reviewed articles on the use of ChatGPT remain limited. This gap prompts a crucial exploration of student-users' perspectives and first-hand experiences using ChatGPT in mathematics tasks and learning within the local context. Many students know ChatGPT and its potential use in academic work. This study's locale is one of the higher institutions in Cebu, Philippines. As awareness grows, ChatGPT has generated excitement and concern across various use cases, signifying the need to create practical guidelines for its use in academia.

The integration of AI in mathematics education, especially for 21st century learners, underscores the importance of considering students' perspectives and experiences in assessing the effectiveness of innovative tools and methods (Bader et al., 2021; Chan & Hu, 2023). Given the scarcity of local studies on this subject, this research aims to address critical knowledge and contextual gaps, delivering valuable insights to the broader research community. Furthermore, this study employs a mixed-method study to gain a comprehensive analysis on the use of ChatGPT, which served as the basis for crafting directional prompts in using the tool for mathematics learning. Specifically, the research seeks to answer the following questions:

1. What is the student's perception level on using ChatGPT as a supplemental learning tool in mathematics in terms of ease of use, relative advantage, compatibility, and intention to use?
2. Is there a significant difference in the perceptions of the students when grouped by gender?
3. How do pre-service teachers use ChatGPT in learning mathematics?
4. What are the specific challenges encountered by the participants while using ChatGPT for mathematics learning?
5. What are the benefits perceived by the participants while using ChatGPT for mathematics learning?

THEORETICAL FRAMEWORK

The researchers anchored their study on four key theoretical frameworks to explore the rising use of ChatGPT in education: the diffusion of innovation (DOI) theory by Rogers (2003, as cited in Okoli and Tewari, 2021), the technology acceptance model (TAM) by Davis (1989) as cited in Yilmaz et al. (2023), the connectivism learning theory by Siemens (2005) as mentioned in Vitoulis (2017), and the community of inquiry (COI) framework by Garrison et al. (1999) as mentioned in ElSayad (2023). These theories provide essential insights into how ChatGPT is adopted, perceived, and applied within educational environments, and they directly inform the study's research questions.

The DOI theory emphasizes how innovations are adopted over time, with five key attributes shaping this process: relative advantage, compatibility, complexity, trialability, and observability. This study focuses on three of these attributes, relative advantage, compatibility, and complexity, to frame the first research question, which examines students' perceptions of ChatGPT in mathematics. The DOI framework also supports the second research question, as adoption factors may vary across demographic groups such as gender.

Relative advantage refers to the perceived benefit of an innovation compared to previous options. ChatGPT's advantage lies in its ability to instantly deliver information, making it a valuable learning supplement, especially for students in remote areas (Raman et al., 2023). Compatibility refers to how well the innovation aligns with users' existing values and experiences. ChatGPT's usefulness depends on how well it fits students' needs and current educational practices (Okoli & Tewari, 2021; Raman et al., 2023). However, concerns have also been raised regarding its potential misuse by students (Deng & Lin, 2023; King, 2023) as cited by Raman et al. (2023), which will be considered under this construct. The third factor, complexity, involves how easy users find the innovation to use. Students widely perceive ChatGPT as user-friendly and accessible (Okoli & Tewari, 2021; Raman et al., 2023).

Complementing DOI, the TAM highlights perceived usefulness (PU) and perceived ease of use (PEOU) as central determinants of technology adoption (Davis, 1989, as cited in Yilmaz et al., 2023). PU refers to the belief that using the technology will enhance learning effectiveness, while PEOU relates to how effortlessly users believe they can use the technology. In this study, TAM reinforces the constructs examined in the first research question, since PU corresponds to relative advantage and PEOU relates to complexity. Moreover, TAM informs the analysis of the second research question by providing a lens for understanding how acceptance patterns may differ among student groups. Thus, TAM supports the evaluation of pre-service teachers' perceptions of ChatGPT's ease of use, usefulness, and trustworthiness in mathematics learning (Yilmaz et al., 2023).

The connectivism learning theory expands the analysis beyond perceptions to the actual use of ChatGPT in mathematics learning. This perspective is directly tied to the third research question, which investigates how pre-service teachers employ ChatGPT as a learning tool. Furthermore, research question 4 and research question 5, which explore the challenges and benefits experienced by students, are informed by connectivism, as these reflect the opportunities and barriers of engaging with digital tools within networked learning environments. The connectivism learning theory, introduced by Siemens (2005, as cited in Vitoulis, 2017), complements the above theories by emphasizing learning through digital networks. It explains how technology enables students to access, create, and share knowledge across the Internet.

Finally, the COI framework provides a model for examining the quality of students' learning experiences with ChatGPT. Its core components, cognitive presence, social presence, and teaching presence, guide the interpretation of the third, fourth, and fifth research questions (Garrison et al., 1999, as cited in ElSayad, 2023; Garrison et al., 2001). For instance, research question 3 aligns with cognitive presence, as it investigates how ChatGPT supports critical engagement with mathematical content. The fourth research question links to both cognitive and teaching presence, as challenges may arise from difficulties in sustaining inquiry or a lack of instructional guidance. Research question 5 connects to perceived benefits, particularly in enhancing social and cognitive presence, where ChatGPT may support reflection, exploration, and collaboration. According to Rüttemann (2019), students must actively participate in reflection and inquiry to develop higher-order thinking skills. ChatGPT may serve as a tool to enhance these learning experiences by encouraging meaningful interaction and exploration in online settings.

Taken together, DOI and TAM establish the foundation for understanding pre-service teachers' perceptions and acceptance of ChatGPT, while connectivism and COI provide the pedagogical and experiential lenses to analyze its practical use, challenges, and benefits. This integration ensures that the study captures both the technological and educational dimensions of ChatGPT as a supplementary tool in mathematics learning.

LITERATURE REVIEW

In today's learner-centric educational system, AI technologies are increasingly emphasized to supplement individual pursuits of knowledge (Molnár & Szűts, 2018). Recent studies highlight ChatGPT's transformative potential in education, emphasizing its ability to personalize learning, develop interactive tutoring programs, and enhance critical thinking skills (Ahmad et al., 2023; Gentile et al., 2023; Moore et al., 2023; Wu & Yu, 2023). ChatGPT's educational benefits include personalized learning, interactive tutoring, critical thinking evaluation, and enhanced usability. It tailors instructional content to individual student interests, abilities, and goals, allowing students to progress at their own pace (Baidoo-Anu & Ansah, 2023; Javaid et al., 2023). This tool also provides real-time feedback, support, and various study tools, enhancing memory retention and learning efficiency (Bonsu & Baffour-Koduah, 2023; Bukar et al., 2023; Javaid et al., 2023; Tam & Said, 2023). Additionally, it offers precise and concise responses that encourage critical evaluation of its output (Javaid et al., 2023). Withal, it has an enhanced usability for its capabilities to engage users in human-like conversation, handle multiple languages, and provide structured explanations (Aljanabi et al., 2023; Frieder et al., 2023; Ruiz et al., 2023; Skjuve et al., 2023; Wardat et al., 2023; Zafrullah et al., 2023). Research further highlights its capacity to adapt exercises and feedback to individual learners, thereby supporting differentiated instruction (AlAli & Wardat, 2024). Taken together, these features suggest that ChatGPT could serve as a valuable supplement to traditional resources, especially in mathematics, where learners often struggle with conceptual understanding.

Building on these general benefits, ChatGPT in mathematics education has attracted particular interest because of its ability to generate step-by-step solutions, clarify concepts, and sustain iterative conversations that mirror tutoring interactions (Azaria et al., 2023; Hasanein & Sobaih, 2023). Its iterative conversational nature allows for ongoing engagement and clarifications, enriching learning experiences (Castillo et al., 2023; Currie, 2023; Ellis & Slade, 2023; Rodríguez et al., 2023; Sallam et al., 2023). Furthermore, ChatGPT encourages independent learning and enhances learner engagement (Elkhodr et al., 2023; Kohnke et al., 2023; Ma, 2023; Nisar & Aslam, 2023). Many authors remain optimistic that ChatGPT could enhance teaching and learning when properly supervised and guided by adequate policies (Silva et al., 2023). This perspective highlights the importance of responsible integration, particularly in mathematics, where the risk of compromising academic ethics and creativity remains a concern (Malinka et al., 2023).

Consequently, there is a need to carefully analyze the use of ChatGPT in education, beginning with students' perceptions of its role as a supplemental learning tool. Numerous studies have highlighted its ability to provide instant, personalized student support (Ahmad et al., 2023; AlAli & Wardat, 2024; Moore et al., 2023). This personalization

is a critical aspect of practical education. ChatGPT can adapt to individual learning needs and provide customized exercises, explanations, and feedback, enhancing engagement and comprehension in mathematics learning (AlAli & Wardat, 2024). Likewise, the availability of real-time assistance for mathematical problems contributes to a better understanding of mathematical concepts (Cobbe et al., 2023). Moreover, the interactive nature of ChatGPT engages students more effectively than traditional resources (Tlili et al., 2023; Zhang & Aslan, 2021, as cited by Javaid et al., 2023; Kooli, 2023), resulting in higher retention of mathematical knowledge and sustained interest in the subject (AlAli & Wardat, 2024). Although these findings demonstrate clear advantages, they are accompanied by equally significant concerns.

For instance, while ChatGPT is an effective tool for learning new concepts and solving math problems, studies have revealed important limitations. Based on the study conducted by Frieder et al. (2023), ChatGPT's mathematical skills are far worse than those of the typical graduate student in mathematics. It frequently understands the question but has trouble coming up with precise answers. This is a significant concern, as students and others who rely on ChatGPT for mathematical assistance could be misled. However, researchers also stressed the importance of users in addressing this issue since the specificity and caliber of user input can affect ChatGPT's response accuracy (AlAli & Wardat, 2024). To ensure their accuracy, it is crucial to carefully go over the generated responses and validate them with other sources (AlAli & Wardat, 2024; Javaid et al., 2023). ChatGPT also raises concerns about the potential for excessive dependence on technology, as noted by Javaid et al. (2023), and a decline in the importance of human interaction within the educational journey, as highlighted by Kooli in 2023. AlAli and Wardat (2024) assert that students relying on ChatGPT for math problem-solving may not nurture the critical thinking and problem-solving skills necessary for academic success and future endeavors.

Beyond these issues, the integration of ChatGPT in mathematics education also raises further concerns. Students may rely too heavily on AI, potentially undermining their ability to think critically and solve problems independently (Javaid et al., 2023; Kooli, 2023). In mathematics specifically, concerns persist about ChatGPT's accuracy in problem-solving, with instances of incorrect or incomplete solutions (Frieder et al., 2023; Wardat et al., 2023). Its limitations in comprehending graphical ideas, complex mathematical concepts, and solving intricate problems further restrict its effectiveness in mathematical reasoning (Dao & Lê, 2023). Despite differences in perspectives and assertions, one commonality among authors is the optimism that ChatGPT, when properly supervised and guided by adequate policies, could enhance teaching and learning (Silva et al., 2023). Researchers emphasize the importance of viewing ChatGPT as a complementary tool rather than a substitute for human teachers (Wardat et al., 2023). Balancing automated assistance with human guidance is crucial (Bahrini et al., 2023; Javaid et al., 2023; Kasneci et al., 2023).

Even so, critical evaluations caution that ChatGPT's performance in mathematics remains inconsistent. Frieder et al. (2023) found that its problem-solving skills fall significantly short of graduate-level mathematical reasoning, with frequent errors in complex or non-routine problems. Dao and Lê (2023) similarly observed limitations in handling graphical and symbolic representations. These findings raise

concerns that over-reliance on ChatGPT may mislead students rather than support them. Importantly, several studies stress that the quality of responses is highly dependent on the specificity of user prompts (AlAli & Wardat, 2024), implying that novice learners, such as pre-service teachers, may not always achieve accurate or pedagogically meaningful outputs.

In addition to accuracy-related challenges, broader risks have been identified. Studies warn that extensive use of ChatGPT in mathematics could encourage procedural dependence, students seeking direct answers instead of engaging in problem-solving processes (Javaid et al., 2023). This aligns with concerns that reliance on AI tools may undermine the development of critical thinking, collaboration, and peer-to-peer interaction, which remain central to mathematics education (Kooli, 2023). From an ethical standpoint, issues of plagiarism, data privacy, and academic integrity persist (Ahmed & Lashari, 2023; Dhingra et al., 2023). These critiques suggest that while ChatGPT has potential benefits, it also risks amplifying the very challenges mathematics educators seek to overcome.

Despite these limitations, scholars converge on the idea that ChatGPT should be framed as a complementary tool rather than a replacement for human instruction (Silva et al., 2023; Wardat et al., 2023). Balancing AI assistance with teacher guidance is particularly critical in mathematics, where conceptual understanding and inquiry-based learning are emphasized. Yet, the literature remains limited in providing discipline-specific insights: most studies address ChatGPT in general educational contexts, with relatively few focusing explicitly on mathematics learning. This gap underscores the need for research that explores how mathematics learners, especially pre-service teachers, perceive and navigate the opportunities and challenges of ChatGPT.

METHODOLOGY

Research Design

This study employed a mixed-method approach, specifically a convergent parallel design described by Labrador and Alderite (2020) as a combination of qualitative and quantitative research methods in a single study. A descriptive quantitative design, which adheres to data collection guidelines without manipulation (Siedlecki, 2020), was utilized through surveys to describe the perception levels of the secondary mathematics pre-service teachers on using ChatGPT in mathematics learning. Concurrently, a descriptive qualitative design provided straightforward descriptions of perceptions without variable manipulation, relying entirely on data-derived codes (Doyle et al., 2019; Lambert & Lambert, 2012; Sandelowski, 2009). The data collection and analysis were done independently with equal emphasis on each method. The researchers integrated the results during the interpretation, exploring convergence, divergence, contradictions, and relationships between the data sources (Razali et al., 2019). Through these combined methods, the study aimed to comprehensively analyze the use of ChatGPT as a supplemental learning tool in mathematics. This mixed-method approach allowed for a more precise and deeper understanding of the problem by integrating quantitative and qualitative data, facilitating a comparative examination that contributed to a thorough understanding of the subject matter (Bengtsson, 2016).

Sample and Data Collection

In the quantitative phase, the respondents of the study were 91 secondary mathematics pre-service teachers of one of the higher institutions in the Philippines, CTU-AC. The number of respondents was determined using Slovin's formula to ensure validity of the sample size (Villaflores, 2021), given the population size of 118 secondary mathematics pre-service teachers with a margin of error of 5%. Subsequently, the researchers employed a proportional stratified random sampling where the pre-service teachers were divided into subgroups according to their year level.

Data were gathered by administering the printed survey questionnaires face-to-face (**Appendix A**). The questionnaire is a combination of adapted questionnaires from Arbaugh et al. (2008), Raman et al. (2023), Fabella (2023), and Yilmaz et al. (2023). Before utilizing the questionnaire, it underwent validity and reliability tests to ensure it was appropriate for the study. Expert content validation demonstrated a high validity index of over 0.85 with S-CVI/Ave of over 0.90 for each variable in terms of both relevance and clarity. Reliability testing with 30 engineering students at the same university revealed significant Cronbach's alpha scores: ease of use (0.77), relative advantage (0.94), compatibility (0.86), intention to use (0.97), and overall instrument reliability (0.96).

The survey was designed to assess the pre-service teachers' perceptions of ChatGPT as a supplemental mathematics learning tool. Data collection involved face-to-face administration using a four-point Likert scale, focusing on key variables including ease of use, compatibility, relative advantage, and intention to use. Participant consent was secured before data gathering, ensuring ethical research practices. Meanwhile, 20 participants were purposely sampled, having interacted with ChatGPT as a tool for mathematics-related tasks, providing saturated insights into the use of ChatGPT as a supplemental learning tool in mathematics, ensuring consistency, reliability, uniformity, and objectivity in data gathering (Garg, 2016). Data was gathered through one-on-one interviews guided by a semi-structured questionnaire. All the procedures were taken with utmost consideration of the ethical standards.

Data Analysis

The quantitative data is analyzed using statistical computations. Frequency counts, simple percentages, and weighted mean were used to provide descriptive statistics on the perception levels of the respondents. Standard deviation was also utilized to assess the variability of pre-service teachers' perceptions of using ChatGPT as a supplemental learning tool. Meanwhile, the researchers examined the verbatim transcriptions of the interviews from the qualitative data collection using thematic analysis, following Braun and Clarke's (2006) six-phase approach of familiarizing with the data, generating initial codes, searching for themes, reviewing themes, defining and naming them, and producing the final report. This iterative process involved repeated reading of transcripts, systematic coding of meaning units, and organizing codes into broader themes that captured patterned responses relevant to the research questions. To ensure reliability and rigor in the analysis, the researchers engaged in reflexive note-taking during coding, revisited data to refine codes and themes, and maintained an audit trail of decisions throughout the process. In addition, peer debriefing was conducted to cross-check emerging themes, and sufficient verbatim extracts were included to enhance credibility and provide transparency in linking data to interpretation.

Table 1. Overall perceptions of pre-service teachers on the use of ChatGPT as a supplemental learning tool in mathematics

Perception variable	Weighted mean (standard deviation)	Categorical response	Verbal description
Ease of use	3.30 (0.70)	Strongly agree	ChatGPT is highly useful
Relative advantage	2.73 (0.73)	Agree	ChatGPT is useful
Compatibility	2.76 (0.75)	Agree	ChatGPT is useful
Intention to use	2.58 (0.75)	Agree	ChatGPT is useful
Totality	2.84 (0.77)	Agree	ChatGPT is useful

Note. Weighted mean intervals: 3.26-4.00 (strongly agree: students perceived ChatGPT as very useful); 2.51-3.25 (agree: students perceived ChatGPT as useful); 1.76-2.50 (disagree: students perceived ChatGPT as less useful); 1.00-1.75 (strongly disagree: students perceived ChatGPT as not useful)

These strategies align with established guidelines for qualitative rigor and strengthen the trustworthiness of the findings by Lincoln and Guba (1985).

FINDINGS/RESULTS

Based on the data gathered, the study presented findings through quantitative, qualitative, and convergent parallel analysis:

Quantitative Data Presentation and Analysis

Based on the quantitative data analysis, the study revealed the overall perception level on using ChatGPT as a learning supplemental tool in mathematics, as shown in **Table 1**. Detailed statistics per variable are presented in **Appendix B**.

The results show consistently positive attitudes across all dimensions. Ease of use received the highest rating with a weighted mean of 3.30, falling in the “strongly agree” category, indicating pre-service teachers find ChatGPT highly useful and user-friendly. The other three variables (relative advantage, compatibility, and intention to use) scored in the 2.58-2.76 range, placing them in the “agree” category, meaning pre-service teachers generally view ChatGPT as useful for mathematics instruction.

The data showed a grand mean of 2.84 and a standard deviation of 0.77 for the four variables attributing to the tool’s usefulness—ease of use, relative advantage, compatibility, and intention to use. This means that most respondents perceived the ease of utilizing the tool and its benefits in their learning experience. Hence, ChatGPT is a useful supplemental learning tool in mathematics.

Qualitative Data Presentation and Analysis

Based on the qualitative data analysis, three major themes emerged regarding the experiences of pre-service mathematics teachers in using ChatGPT:

1. Intentions in using ChatGPT in mathematics
2. Challenges in using ChatGPT in mathematics learning
3. Benefits of using ChatGPT in mathematics learning
4. Prompting methods

Each theme is described below, with sub-themes identified through thematic coding. Representative sample statements and detailed coded excerpts are presented in **Appendix C**, **Appendix D**, **Appendix E**, and **Appendix F** to maintain clarity and brevity in the main manuscript.

Intentions in using ChatGPT in mathematics

The participants reported varied intentions for using ChatGPT, primarily as a supplemental learning tool, a means for collaborative problem-solving, and advanced mathematics support. It was also widely

used as a task assistant. Notably, ChatGPT was leveraged to enhance understanding of complex mathematical concepts (65%), verify solutions (25%), and facilitate advanced topic engagement (80%), particularly in subjects like integral calculus, abstract algebra, and geometry (see **Appendix C** for sub-themes, descriptions, and sample participant statements).

Challenges in using ChatGPT in mathematics learning

Participants identified several challenges, including issues with input and interface limitations, overreliance on ChatGPT, and concerns with accuracy and reliability. Other concerns involved misalignment with classroom instruction and technical or connectivity problems. These challenges highlight the need for critical and guided use of AI tools in educational settings (see **Appendix D** for sub-themes and illustrative participant quotes).

Benefits of using ChatGPT in mathematics learning

Despite the challenges, participants acknowledged various benefits. ChatGPT contributed to enhanced efficiency in task completion, improved cognitive presence, and greater accessibility of support for mathematics learning. Participants noted the tool’s capacity to provide immediate feedback, multi-language assistance, and step-by-step explanations, making it a valuable aid in basic and higher-level mathematics (see **Appendix E** for detailed descriptions and representative participant responses).

Prompting methods

Interacting with ChatGPT relies heavily on formulating prompts, significantly affecting the quality and relevance of responses. Users have developed various prompting methods, such as direct input and copying, where 25% of participants preferred copying and pasting questions directly to preserve intent. Specific prompt construction involves careful wording to guide ChatGPT accurately, a method adopted by 80% of participants. Additionally, response-based prompt adjustment is an iterative approach where users refine their questions based on initial responses, allowing for more accurate answers. This method highlights the importance of adapting prompts to steer conversations and request more precise explanations when needed (see **Appendix F** for detailed descriptions and representative participant responses).

Convergence of Quantitative and Qualitative Results

The evaluation of ChatGPT as a supplemental learning tool in mathematics among Secondary mathematics Pre-service teachers brought to light various convergent and divergent points between the quantitative and qualitative data.

Table 2. Perceived advantages in using ChatGPT as a supplemental learning tool in mathematics

Sub-themes	Quantitative result	Qualitative result	Convergence/divergence
Ease of use	Secondary mathematics pre-service teachers perceived ChatGPT as very easy to use ($\mu = 3.30$).	Various input and interface challenges were noted by the participants, yet they perceived enhanced efficiency in task completion and learning. This shows how ChatGPT facilitates faster learning and task completion, including its perceived accessibility and ease of use.	Convergence: Both data sets strongly indicate that ChatGPT is very easy to use and highly accessible. Divergence: While quantitative data showed high scores for ChatGPT's user-friendliness, ease of use, and accessibility, qualitative insights revealed specific challenges: -About 45% noted dependence on Internet connection strength -About 20% mentioned difficulties with the input interface, particularly for visual aids or diagrams -About 10% found inputting complex mathematical expressions inconvenient
Critical thinking and evaluation	Secondary mathematics pre-service teachers perceived ChatGPT as less beneficial in enabling critical evaluation of responses ($\mu = 2.49$).	Students perceived errors as opportunities to engage in critical thinking and verification, indirectly enhancing their approach to mathematical challenges.	Divergence: ChatGPT may not directly promote critical thinking as measured quantitatively, but inadvertently encourages critical evaluation skills, as revealed in the qualitative data.
Enhanced efficiency in learning	Secondary mathematics pre-service teachers perceived ChatGPT as compatible with learning ($\mu = 2.77$) and beneficial in efficient learning ($\mu = 2.72$).	ChatGPT was commended by the participants for facilitating faster learning, citing its accessibility across various devices and 24/7 availability as key factors, with the caveat of requiring an Internet connection.	Convergence: Both data sets indicate ChatGPT's benefit in enhancing efficiency in learning.
Enhanced efficiency in task completion	Secondary mathematics pre-service teachers perceived ChatGPT as highly compatible with various devices ($\mu = 3.45$), immediately provided comprehensive answers ($\mu = 2.60$, and improved the quality of work ($\mu = 2.91$).	Participants noted the benefit of immediate task completion with ChatGPT, whether seeking quick responses, assistance, or ideas. They highlighted that they can finish a specific assignment or activity in Mathematics promptly and accurately through the tool's capabilities.	Convergence: Both data sets indicate ChatGPT's benefit in enhancing efficiency in task completion.
Benefits on problem-solving	Secondary mathematics pre-service teachers perceived ChatGPT as beneficial in providing step-by-step solutions ($\mu = 3.04$)	About 40% asserted that they benefited from ChatGPT's capability to provide step-by-step guides.	Convergence: Both data sets emphasize Chat-GPT's strength in detailed procedures for problem-solving and explanation and in improving query refinements.

Perceived advantages in using ChatGPT as a supplemental learning tool in mathematics

Based on a mixed-methods analysis of pre-service secondary mathematics teachers' perceptions, significant advantages emerged in using ChatGPT as a supplemental learning tool in mathematics. The study identified four primary perceived advantages: ease of use, critical thinking and evaluation, enhanced efficiency (in both learning and task completion), and problem-solving benefits (Table 2).

Ease of use emerged as a key theme, and both data sets strongly indicated ChatGPT's high accessibility and user-friendliness. While quantitative results reflected high scores in ease of use, qualitative feedback highlighted specific implementation challenges, including reliance on Internet connection strength (45%), difficulties with input interfaces for visual aids (20%), and inconveniences in inputting complex mathematical expressions (10%). When analyzing critical thinking and evaluation, the data sets diverged notably. Quantitatively, ChatGPT was perceived as less beneficial in promoting critical thinking. However, qualitative data provided a more nuanced perspective, suggesting that engaging with errors in ChatGPT's responses fostered essential evaluation skills among students.

In terms of enhanced efficiency, convergence was found in both data sets, indicating that ChatGPT facilitates faster and more effective learning and task completion. This efficiency was attributed to its cross-device accessibility and 24/7 availability, despite Internet connectivity requirements. Both data sets highlighted ChatGPT's ability to

immediately provide comprehensive answers, improving task completion quality and speed.

Problem-solving benefits emerged as another significant theme, with convergence between quantitative and qualitative data emphasizing ChatGPT's strength in providing detailed, step-by-step solutions and supporting query refinements. This indicated its substantial utility in supporting mathematical problem-solving processes.

Perceived challenges in using ChatGPT as a supplemental learning tool in mathematics

The mixed-methods analysis of pre-service secondary mathematics teachers' perceptions uncovered significant challenges in using ChatGPT as a supplemental learning tool in mathematics. The study identified three primary challenges: accuracy and reliability, dependency and reliance, and complementing classroom instruction. While quantitative data revealed concerning low scores for reliability ($\mu = 2.29$) and independent learning compatibility ($\mu = 2.44$), these challenges were strongly corroborated by qualitative insights where participants expressed significant concerns about ChatGPT's mathematical accuracy and its potential to foster student dependency. Notably, a critical divergence emerged in the challenge of classroom instruction compatibility. Despite moderate quantitative scores suggesting acceptable classroom integration ($\mu = 2.55$), qualitative responses highlighted substantial concerns about the misalignment between ChatGPT's problem-solving approaches and traditional pedagogical methods (Table 3).

Table 3. Perceived challenges in using ChatGPT as a supplemental learning tool in mathematics

Sub-themes	Quantitative result	Qualitative result	Convergence/divergence
Accuracy and reliability	Secondary mathematics pre-service teachers perceived ChatGPT as less beneficial in terms of its reliability and accuracy ($\mu = 2.29$)	All participants expressed concerns about the reliability of Chat-GPT's responses, particularly for accurate mathematical solutions.	Convergence: Both data sets consistently reveal concerns about reliability and accuracy.
Dependency and reliance	Secondary mathematics pre-service teachers perceived ChatGPT as less compatible in enabling independent learning ($\mu = 2.44$).	Dependency and reliability emerged as common drawbacks perceived by the participants when using ChatGPT.	Convergence: Both data sets revealed the potential of ChatGPT in increasing students' dependency and reliance on using the tool in mathematics.
Complementing classroom instruction	Secondary mathematics pre-service teachers perceived ChatGPT as compatible with classroom instruction ($\mu = 2.55$)	Mathematics secondary pre-service teachers noted ChatGPT's responses and processes misaligned with those known and presented by teachers and books.	Divergence: Quantitative data indicates a moderate level of perceived compatibility with classroom instruction, suggesting a favorable view of ChatGPT's potential use, however, the qualitative data reveals significant practical concerns for explicitly reporting misalignment between the tool's mathematical approaches and traditional teaching methods.

Intention to use ChatGPT as a supplemental learning tool in mathematics

Pre-service teachers of secondary mathematics showed a positive intention to use ChatGPT in their teaching, though with notable nuances across quantitative and qualitative data. Quantitative measures indicated a moderate intention to use the tool ($\mu = 2.58$), while qualitative findings revealed that approximately 75% of teachers expressed plans to incorporate ChatGPT, with an emphasis on critical evaluation and cross-validation of its responses. While the data sets converged in showing an overall positive intention to use ChatGPT, there were some important divergences. Despite the general openness to the tool, qualitative data uncovered significant concerns, with 80% of teachers expressing worry about potential over-reliance and academic integrity issues. These concerns strongly emphasized the importance of responsible usage and the need to verify information from multiple sources.

DISCUSSION

Quantitative and qualitative data provide valuable insights into pre-service teachers' perceptions and experiences with ChatGPT in mathematics learning. While quantitative data offer a broader view of overall perceptions, qualitative data provide deeper insights into specific intentions, challenges, and benefits.

Based on the quantitative and qualitative data, findings first indicate that pre-service teachers generally find ChatGPT easy to use, with an overall mean of 3.69, as emphasized by about 80% of the participants. Both data sets show a high general agreement on the tool's user-friendliness, with an overall mean of 3.52, as emphasized by 75% of the participants, highlighting its accessibility across various devices and availability at any time. This implies that the pre-service teachers perceived the ease of navigating and interacting with ChatGPT. This aligns with previous studies by Ngo (2023) and Shoufan (2023), which found that students perceive ChatGPT as easy to use due to its simplicity and convenience. This is also consistent with several studies highlighting the numerous advantages of using ChatGPT in learning, including improving accessibility on various devices such as mobile phones and computers, and by providing students with 24/7 information accessibility and assistance, promoting the efficient learning experience by offering personalized support (Alafnan et al., 2023; Obaid et al., 2023; Rahman & Watanobe, 2023). These findings

support ubiquitous learning, where learning environments extend beyond traditional settings into everyday life (Cárdenas-Robledo & Peña-Ayala, 2018).

However, alongside this general perception of ease of use, the data also highlighted practical limitations. Qualitative data revealed that about 45% of participants stressed that while ChatGPT is available anytime, the tool's optimal performance depends on the strength of the Internet connection. This is supported by the study of Aithal and Aithal (2023), revealing that ChatGPT's functionality depends on Internet connectivity and may be inaccessible in areas with limited or no Internet. The impact of connectivity issues is particularly pronounced in environments where Internet stability is not guaranteed, such as schools with inadequate infrastructure (Bekou et al., 2024). As highlighted by several participants, the ability to provide timely responses is significantly hindered when network conditions are poor. This sentiment is echoed by Božić and Poola (2023), noting that the requirement for high-speed Internet and other technological resources can be a barrier for some schools and students.

In addition to connectivity, participants also raised concerns about interaction challenges. Some students emphasized the input and user interface challenges, highlighting the varying difficulties encountered when interacting with ChatGPT, including the inability to input or receive visual aids like diagrams or examples, especially for areas that benefit from visual representations (20% of the participants). This is consistent with various studies positing the need for improved interface design to facilitate more accurate and efficient interactions (Azam, 2023; Kim et al., 2024; Nah et al., 2023). Moreover, inaccurately putting complex mathematical expressions can be inconvenient (10%), leading to potential misunderstandings. Unclear, ambiguous, or incorrectly phrased prompts can result in irrelevant or incorrect responses (60%). This is consistent with the study of Cronjé (2023) positing that constructing well-designed prompts is essential to achieving desired outcomes (Azaria et al., 2023). This also aligns with the assertion of Gnewuch et al. (2018), who emphasize the role of clarity and specificity in improving AI performance on tasks by enhancing the AI's understanding of the query. Similarly, accurate answers can be generated if the prompts are constructed specifically (Liu et al., 2024) and include details such as instructions, context, input data, and output indicators (Li, 2023). This finding denotes that providing comprehensive guidance is crucial for leveraging ChatGPT's abilities to generate accurate and relevant responses.

Related to these usability issues, the complexity of ChatGPT's language also presented barriers. The complex language used by ChatGPT may be difficult for some users to understand (40%), leading to confusion and difficulty in understanding (Young & Shishido, 2023), a barrier to effective communication between the tool and the user. It also hinders accessibility, particularly for those with limited education or literacy, and exacerbate information access inequalities (Amin, 2023). Moreover, it shows the importance of cultural and linguistic sensitivity, recognizing that what may be considered complex in one context might be perfectly understandable in another (Zheng & Stewart, 2024). Nevertheless, this requires the user to have good prompting skills to simplify interactions. This aligns with various studies, such as those by Ekin (2023), White et al. (2023), and Getenet (2024), highlighting the significance of prompt engineering or crafting prompts to generate desired responses from ChatGPT. These studies acknowledge that modifying or adjusting prompts is necessary if the desired output is unmet initially. Furthermore, insights from Haque (2023), Ekin (2023), and Bozkurt and Sharma (2023) suggest that ChatGPT can respond in more straightforward terms and a more human-like manner, depending on the prompts given. This reinforces the idea that prompt adjustment can help users obtain responses tailored to their needs and understanding.

Beyond ease of use and communication, the findings also touched on critical thinking and evaluation. ChatGPT was acknowledged by the participants for its explicit and implicit role in promoting critical thinking and enhancing their cognitive presence. By offering a wide range of answers and encouraging the evaluation of alternative problem-solving methods, ChatGPT empowered learners to explore concepts beyond surface-level understanding. This aligns with various studies highlighting ChatGPT's role that extends beyond knowledge dissemination to nurturing higher-order thinking skills (An et al., 2023; Ellis & Slade, 2023; Sánchez, 2023). Through its analytical capabilities and question-answer interactions, it guides learners in problem-solving, fosters critical thinking, and encourages the application of knowledge (Lieberman, 2023; Luan et al., 2023; Mogavi et al., 2024). This positive reception of ChatGPT's assistance underscores the potential of AI tools. They complement traditional teaching methods and provide accessible, user-friendly platforms for learners.

Nevertheless, contradictions were also evident between the quantitative and qualitative results. Positive results diverge from the quantitative findings that showed respondents expressing lower levels of agreement with ChatGPT's ability to help them critically evaluate answers and solutions. According to Azaria et al. (2023), ChatGPT often exhibits a high level of confidence when responding, even in cases where the information is incorrect. Consequently, students usually accept the information provided without much critical thought (Deiana et al., 2023). This tendency is notable and emphasizes critically evaluating the tool's outputs (Azaria et al., 2023; Sullivan et al., 2023; Sušnjak, 2022). Additionally, several scholars posited that ChatGPT cannot ask targeted, in-depth questions that stimulate critical thinking and encourage individuals to reflect on their perspectives (Dasari et al., 2024; Huang, 2023). It cannot engage in dialectical exchanges and refine concepts collaboratively with students (Loos et al., 2023) and in inductive reasoning processes (Echenique, 2023), limiting the depth of critical thinking and self-reflection. Nevertheless, these emphasize the importance of balancing technological reliance with essential evaluation skills, ensuring learners remain active participants in their educational journey.

Alongside critical thinking, both data sets also revealed convergence on efficiency in learning. Convergence in both data sets was found indicating that ChatGPT facilitates faster and more efficient learning. This was attributed to its accessibility across devices and its 24/7 availability, despite the necessity of an Internet connection. ChatGPT's ability to provide quick responses and generate ideas enabled them to accomplish tasks promptly while consuming less time. This is consistent with the study of An et al. (2023), which posited the reduced time students spend retrieving information as ChatGPT consolidates information from multiple sources, delivering concise responses and saving learners time in their learning journey (Hasanein & Sobaih, 2023; Kaiss et al., 2023; Li et al., 2023). The capability to receive relevant and instantaneous assistance empowers learners to complete tasks more efficiently, reducing the time investment required (Adiguzel et al., 2023; Getenet, 2024; Mogavi et al., 2024; Rueda et al., 2023).

Apart from enhanced efficiency in learning, another enhanced efficiency was found in completing mathematical-related tasks. Both data sets converged to highlight ChatGPT's compatibility with various devices and its ability to immediately provide comprehensive answers, thereby improving the quality and speed of task completion. These align with the broader notion that AI and adaptive learning technologies such as ChatGPT (Jepkemoi et al., 2024; Rasul et al., 2023; Strzelecki, 2023) can facilitate efficient and personalized learning experiences (An et al., 2023; El-Sabagh, 2021; Hasanein & Sobaih, 2023; Jepkemoi et al., 2024). E-learning (e.g., use of AI tools) has proven to produce desirable outcomes by enabling students to access it anytime and anywhere (Chen et al., 2020; El-Sabagh, 2021; Lee et al., 2019; Luan et al., 2023). Furthermore, these are consistent with Luan et al.'s (2023) highlighting the critical reasons for ChatGPT adoption in educational settings: PU and PEOU of Davis' (1985) TAM (as cited by Luan et al., 2023). He posited that there is no doubt that ChatGPT users will improve their task completion, increase learning efficiency, save time, and improve their performance and quality, all of which are emphasized by TAM as advantageous.

Another key theme was found as the benefits in problem-solving were evident, with convergence between quantitative and qualitative data emphasizing ChatGPT's strength in providing detailed, step-by-step solutions and enhancing query refinements. This indicated its utility in supporting problem-solving processes. This finding aligns with the primary purpose of ChatGPT, which is to explain and break down complex tasks into manageable steps, making it a valuable tool for mathematical problem-solving. This is consistent with various studies, positing that ChatGPT is beneficial for providing step-by-step explanations and solutions to math problems, enhancing understanding and problem-solving strategies in mathematics (Azaria et al., 2023; Hasanein & Sobaih, 2023; Mogavi et al., 2024). By breaking down complex concepts into understandable components and offering clarifications (Azaria et al., 2023; Coskun, 2023; Mogavi et al., 2024). However, contradictory evidence also exists, such as Frieder et al. (2023), who reported that ChatGPT often fails to provide correct solutions, performing below the level of an average mathematics graduate student.

These concerns about accuracy and reliability were echoed strongly in both data sets. Both data sets highlight challenges and concerns, such as reliability and accuracy issues (100%). Both data sets revealed learners being concerned with reliability and accuracy of ChatGPT's responses

gaining unfavorable mean score of 2.29, and participants consistently expressed dissatisfaction with ChatGPT's performance in delivering correct mathematical solutions (80%). This suggests that while ChatGPT may excel in presenting step-by-step solutions, users may still have concerns about the trustworthiness of the information it provides and its ability to comprehensively enhance their mathematical understanding. This aligns with various existing findings where students show high confidence in ChatGPT's step-by-step solutions but express concerns about its trustworthiness (Azaria et al., 2023; Ruiz et al., 2023; Szabo, 2023; Wardat et al., 2023). The students expressed lower levels of agreement with the tool's overall accuracy, reliability, and impact on mathematical learning experiences (Chan et al., 2023; Frith, 2023; Gill et al., 2024; Lo, 2023; Ruiz et al., 2023).

Withal, dependency and reliance is also revealed as a common drawback in its use for learning mathematics. This was evident in the quantitative results as well as echoed in qualitative insights. ChatGPT was rated low (2.44) for its ability to enable independent learning, implying that users did not find it particularly empowering for self-study. Similarly, the qualitative data reveal a concern about fostering dependency, which might hinder independent learning further (80%). This is consistent with various studies showing students have a concerning level of dependency to ChatGPT (Rane et al., 2023), demonstrating a reliance on external tools rather than personal knowledge and skills (Iqbal et al., 2022). It indicates a lack of integrity and suggests a user may not value academic honesty (Sullivan et al., 2023). Additionally, the study of Sok and Heng (2023) highlighted that advanced AI models like ChatGPT can create highly realistic text with minimal input, raising concerns among users even potential cheating in exams. ChatGPT has the potential to generate human-like text, making it easier for users to plagiarize content or receive assistance (Nah et al., 2023). That is why there is a need for more research to understand the impact of AI models like ChatGPT and develop ways to prevent any overreliance (Michel-Villarreal et al., 2023; Rahman & Watanobe, 2023).

Divergences also appeared when considering classroom instruction. Quantitative results suggested moderate compatibility with classroom instruction. In contrast, qualitative feedback raised significant concerns about the misalignment between ChatGPT's mathematical approaches and traditional teaching methods used in classrooms and textbooks. This discrepancy warrants thorough examination from both methodological and pedagogical perspectives. The quantitative data's suggestion of moderate compatibility may reflect surface-level integration potential, such as content delivery or practice opportunities. However, the qualitative insights reveal fundamental challenges in pedagogical alignment that could significantly impact student learning outcomes.

The reported misalignment between ChatGPT's problem-solving approaches and traditional teaching methods raises critical questions about cognitive load and instructional coherence. When students encounter divergent methodological approaches, they may experience increased cognitive burden as they attempt to reconcile these differences. This cognitive strain could potentially impede learning efficiency and conceptual understanding, particularly for students who require consistent instructional scaffolding. This is consistent with the position of various scholars noting that when students are presented with multiple approaches to solving the same problem, it can create uncertainty about which method to trust or follow. This confusion can

hinder their understanding and retention of the material (Labadze et al., 2023; Yee et al., 2023). The inconsistency may lead to skepticism about the reliability and accuracy of ChatGPT's responses, as students might be unsure about the credibility of an unfamiliar approach compared to the well-established methods taught by their instructors (Amos, 2023).

Nevertheless, despite its limitations, the Intention to use ChatGPT was positively reflected in both data sets, although qualitative insights revealed more nuanced concerns about over-reliance and academic integrity issues. This denotes that ChatGPT is a valuable learning tool. This finding is consistent with the finding of Choudhury and Shamszare (2023) investigating the adoption and use of ChatGPT, which revealed that students have a high intention level of utilizing the tool. Likewise, this is evident with the findings of Hasanein and Sobaih (2023) revealing that the majority of students have a positive view of ChatGPT use for academic purposes in their higher education. Despite the overall positive intention to use ChatGPT in mathematics learning among pre-service teachers, there is still a need to address skeptical opinions and perceived challenges to ensure the successful implementation and widespread adoption of ChatGPT in educational settings (Hasanein & Sobaih, 2023; Lo, 2023; Rawas, 2023).

Subsequently, both data sets emphasize that the tool must be leveraged as a supplemental learning tool, not a definitive source of information and tool for easy learning. These findings reveal that while ChatGPT has notable strengths in accessibility and enhancing learning efficiency, it also presents challenges that require careful consideration and responsible use to mitigate dependency and ensure academic integrity. Furthermore, both highlight the learners' role as users; whether ChatGPT's impact is beneficial or harmful depends on its implementation, and the balance users strike between its potential benefits, challenges, and risks. Regarding the latter, training students in the ethical and responsible use of ChatGPT, its potential and limitations (considering that it only complements learning), and the ability to formulate clear and specific prompts and verify the responses is imperative. Going forward, incorporating improvements that address the limitations, challenges, and issues identified and fostering an ecosystem that promotes active learning and critical inquiry will be crucial in maximizing the potential benefits of ChatGPT in educational contexts. Future research should explore the implications of AI tools in diverse educational contexts, aiming to maximize their potential in facilitating effective and engaging learning experiences.

CONCLUSION

Secondary mathematics pre-service teachers viewed ChatGPT positively as a supplemental learning tool in mathematics highlighting its ease of use, relative advantage, compatibility, and intention to use. The study revealed several educational advantages, such as making learning more efficient, enhancing thinking skills, and tailoring to individual learning needs. However, results also showed some drawbacks, including occasional errors, limited functionality, and the potential for over-reliance. Thus, it was revealed that ChatGPT should serve as a tool that supplements learning rather than the main source of information. These results align with the TAM, emphasizing that the advantages of a tool and the high possibility of adoption resonate from its PU and PEOU. This is also consistent with the COI, emphasizing cognitive presence, as the learners deepen their comprehension of mathematical concepts and create new information through sustained

conversation with the tool. Central to connectivism theory, learning is no longer solely about knowledge transfer but instead creating and curating knowledge, wherein tools in the e-learning arena can play a significant role. It is also consistent with the DOI theory, noting that the tool's simplicity, ability to outperform other technologies, adaptability to learners' needs, and accepted norms in education were essential factors in its adoption. The contribution of this study lies in bridging these theoretical perspectives with empirical evidence from mathematics education, an area where research on ChatGPT remains limited. These contributions provide a foundation for future studies to critically explore AI adoption in mathematics education and inform teacher preparation programs on how to guide ethical, effective, and pedagogically sound use of emerging AI tools.

Recommendation

Based on the findings of the study, it is recommended for institutions to organize training programs, seminars, workshops, and online courses for teachers and students to improve their understanding of ChatGPT, its latest features, strengths, and weaknesses particularly in mathematics. Teachers should constantly remind their students about ChatGPT's ethical use and emphasize that it is a tool to support learning, not replace it. Students should verify information, especially for advanced math problems, by cross-checking with reliable sources. Furthermore, curriculum developers and policymakers should explore ways to integrate ChatGPT into education as a supplementary resource, not a replacement for traditional teaching and learning methods. This approach can enhance learning experiences, especially in mathematics, while ensuring ethical and effective use of the tool. To support these initiatives, the distribution of customized guidebooks for effective ChatGPT prompting is essential for all stakeholders. Future research should concentrate on conducting longitudinal studies to examine ChatGPT's long-term impact on mathematical skills and explore its potential applications across other academic fields.

Limitations of the Study

This study employed a mixed-method convergent parallel design to analyze the use of ChatGPT as a supplemental tool in mathematics, aiming to provide a nuanced perspective by addressing the limitations of each method. However, several constraints must be noted. The reliance on self-reported quantitative and qualitative data raises the possibility of social desirability bias, while the focus on mathematics education students limits generalizability to other populations. The study's timeframe also posed challenges, as qualitative methods require considerable time for interviews, transcription, and validation, and the simultaneous use of quantitative and qualitative approaches demanded significant resources. Moreover, while quantitative data may offer broader applicability, qualitative findings are context-specific, and combining both approaches can affect generalizability and depth. These limitations were considered in interpreting the results, and future research should aim to address them to strengthen and extend the findings.

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Ethics declaration: In accordance with the university guidelines, ethics committee review was not sought for this study because it involved a minimal-risk, anonymous survey and did not collect any direct personal identifiers, such as names, addresses, contact details. Informed consent were sought and participation was voluntary. Participants were provided with the study purpose, procedures, risks/benefits, and data handling. Completion/submission of the survey was taken as evidence of informed consent. To protect confidentiality, responses were anonymized. The research questions were validated by experts to ensure relevance and clarity.

AI statement: The authors stated that Grammarly was used for grammar and style enhancement and ChatGPT was used for vocabulary refinement and conceptual development during the preparation of this manuscript.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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APPENDIX A: RESEARCH INSTRUMENT

Perceptions of Pre-Service Teachers on the Use of ChatGPT

Directions: Please put a check mark (/) on the box that corresponds to the degree or extent to which you agree or disagree based on the given statements using the following scales: 1–Strongly disagree (not useful), 2–Disagree (less useful), 3–Agree (useful), and 4–Strongly agree (highly useful).

Table A1. Perceptions of pre-service teachers on the use of ChatGPT

Statements	1	2	3	4
A. Ease of use (adapted from Yilmaz et al., 2023 [1-3] and Raman et al., 2023 [4-7])				
The individual's perception of how difficult or simple it is to use ChatGPT.				
1. ChatGPT is easy to use.				
2. ChatGPT can do what I want it to do.				
3. ChatGPT is a user-friendly tool.				
4. ChatGPT can easily pick up prompts.				
5. ChatGPT can be used anytime and anywhere.				
B. Relative advantage (adapted from Arbaugh et al., 2008 [1-3], Raman et al., 2023 [11], Yilmaz et al., 2023 [9, 14, 15], Fabella, 2023 [5, 7, 13] and researcher-made [4, 6, 8, 10, 12])				
This measures the ability of ChatGPT to outperform other technologies through its responses' factuality, clarity, structure, depth, and adherence, as well as its ability to enhance cognitive presence.				
1. ChatGPT is valuable in helping me comprehend lessons in mathematics.				
2. ChatGPT is useful in providing further explanations to enrich my learning in mathematics.				
3. ChatGPT helps answer mathematical problems.				
4. ChatGPT enables me to critically distinguish what are correct and incorrect methods for problem-solving.				
5. ChatGPT enables me to make additional and critical adjustments to my questions until I get the desired response.				
6. ChatGPT provides content that is clear and easy to understand.				
7. ChatGPT can give step-by-step solutions to math problems.				
8. ChatGPT consistently supplies relevant answers to questions.				
9. ChatGPT provides accurate and reliable information.				
10. My mathematical learning experience has improved because of ChatGPT.				
11. ChatGPT provides better experiences compared to other AI technologies I have used.				
12. ChatGPT uses prior interactions within the same prompt tree to provide personalized responses.				
13. ChatGPT keeps information secured.				
C. Compatibility (adapted from Raman et al., 2023 [4-6] and researcher-made [1-3, 7-12])				
This refers to ChatGPT's ability to adapt to the learners' needs and accept educational norms.				
1. ChatGPT is compatible across various devices, allowing me to access it from smartphones, tablets, or computers.				
2. ChatGPT can understand questions using vernacular language.				
3. ChatGPT fits very well into my learning style.				
4. ChatGPT improves the quality of my work.				
5. ChatGPT makes learning mathematics fun.				
6. ChatGPT complements the teaching methods used by my professors.				
7. ChatGPT enables me to learn math independently.				
8. ChatGPT is a valuable resource for immediately obtaining comprehensive answers to math problems.				
D. Intention to use (adapted from Raman et al., 2023)				
This refers to the likelihood of students to use ChatGPT.				
1. I like to use ChatGPT to clarify complex mathematical concepts.				
2. I like to use ChatGPT to enhance my mathematical skills.				
3. I want to use ChatGPT to aid my learning process in mathematics.				

APPENDIX B: QUANTITATIVE DATA PRESENTATION AND INTERPRETATION ON EASE OF USE, COMPATIBILITY, RELATIVE ADVANTAGE, AND INTENTION TO USE

Table B1. Perceptions of pre-service teachers on the use of ChatGPT as to ease of use

Indicators	Male		Female		Overall		
	WM	D	WM	D	WM	SD	D
1. ChatGPT is easy to use.	3.55	Very easy to use	3.73	Very easy to use	3.69	0.46	Very easy to use
2. ChatGPT can do what I want it to do.	2.90	Easy to use	3.14	Easy to use	3.09	0.64	Easy to use
3. ChatGPT is a user-friendly tool.	3.25	Easy to use	3.59	Very easy to use	3.52	0.56	Very easy to use
4. ChatGPT can easily pick up prompts.	3.05	Easy to use	3.14	Easy to use	3.12	0.68	Easy to use
5. ChatGPT can be used anytime and anywhere.	3.05	Easy to use	3.11	Easy to use	3.10	0.86	Easy to use
Totality	3.16	Students perceived ChatGPT as easy to use	3.34	Students perceived ChatGPT as very easy to use	3.30	0.70	Students perceived ChatGPT as very easy to use

Note. WM: Weighted mean; D: Description; SD: Standard deviation; Weighted mean intervals: 3.26-4.00 (strongly agree: students perceived ChatGPT as very easy to use); 2.51-3.25 (agree: students perceived ChatGPT as easy to use); 1.76-2.50 (disagree: students perceived ChatGPT as less easy to use); 1.00-1.75 (strongly disagree: students perceived ChatGPT as not easy to use)

Table B2. Perceptions of pre-service teachers on the use of ChatGPT as to compatibility

Indicators	Male		Female		Overall		
	WM	D	WM	D	WM	SD	D
1. ChatGPT is compatible with various devices, allowing me to access it from smartphones, tablets, or computers.	3.40	Highly compatible	3.46	Highly compatible	3.45	0.65	Highly compatible
2. ChatGPT can understand questions using vernacular language.	3.00	Compatible	3.08	Compatible	3.07	0.76	Compatible
3. ChatGPT fits very well into my learning style.	2.60	Compatible	2.61	Compatible	2.60	0.63	Compatible
4. ChatGPT improves the quality of my work.	2.75	Compatible	2.97	Compatible	2.91	0.64	Compatible
5. ChatGPT makes learning mathematics fun.	2.55	Compatible	2.42	Less compatible	2.45	0.67	Less compatible
6. ChatGPT complements the teaching methods used by my professors.	2.55	Compatible	2.55	Compatible	2.55	0.64	Compatible
7. ChatGPT enables me to learn math independently.	2.45	Less compatible	2.44	Less compatible	2.44	0.70	Less compatible
8. ChatGPT is a valuable resource for immediately obtaining comprehensive answers to math problems.	2.75	Compatible	2.56	Compatible	2.60	0.71	Compatible
Totality	2.76	Students perceived ChatGPT as compatible to learning	2.76	Students perceived ChatGPT as compatible to learning	2.76	0.75	Students perceived ChatGPT as compatible to learning

Note. WM: Weighted mean; D: Description; SD: Standard deviation; Weighted mean intervals: 3.26-4.00 (strongly agree: students perceived ChatGPT as highly compatible to learning); 2.51-3.25 (agree: students perceived ChatGPT as compatible to learning); 1.76-2.50 (disagree: students perceived ChatGPT as less compatible to learning); 1.00-1.75 (strongly disagree: students perceived ChatGPT as not compatible to learning)

Table B3. Perceptions of pre-service teachers on the use of ChatGPT as to relative advantage

Indicators	Male		Female		Overall		
	WM	D	WM	D	WM	SD	D
1. ChatGPT is valuable in helping me comprehend lessons in mathematics.	2.70	Beneficial	2.83	Beneficial	2.80	0.76	Beneficial
2. ChatGPT is useful in providing further explanations to enrich my learning in mathematics.	2.90	Beneficial	3.00	Beneficial	2.98	0.70	Beneficial
3. ChatGPT is helpful in answering mathematical problems.	2.55	Beneficial	2.75	Beneficial	2.70	0.64	Beneficial
4. ChatGPT enables me to critically distinguish what are correct and incorrect methods for problem-solving.	2.50	Less beneficial	2.49	Less beneficial	2.49	0.62	Less beneficial
5. ChatGPT enables me to make additional and critical adjustments to my questions until I get the desired response.	2.95	Beneficial	3.04	Beneficial	3.02	0.70	Beneficial
6. ChatGPT provides content that is clear and easy to understand.	2.85	Beneficial	2.87	Beneficial	2.87	0.73	Beneficial
7. ChatGPT can give step-by-step solutions to math problems.	3.00	Beneficial	3.06	Beneficial	3.04	0.71	Beneficial
8. ChatGPT consistently supplies relevant answers to questions.	2.45	Less beneficial	2.73	Beneficial	2.67	0.70	Beneficial
9. ChatGPT provides accurate and reliable information.	2.10	Less beneficial	2.34	Less beneficial	2.29	0.64	Less beneficial
10. My mathematical learning experience has improved because of ChatGPT.	2.10	Less beneficial	2.34	Less beneficial	2.29	0.65	Less beneficial

Table B3 (Continued).

Indicators	Male		Female		Overall		
	WM	D	WM	D	WM	SD	D
11. ChatGPT provides better experiences compared to other AI technologies I have used.	2.70	Beneficial	2.69	Beneficial	2.69	0.73	Beneficial
12. ChatGPT uses prior interactions within the same prompt tree to provide personalized responses.	2.75	Beneficial	2.89	Beneficial	2.86	0.66	Beneficial
13. ChatGPT keeps information secured.	2.75	Beneficial	2.82	Beneficial	2.80	0.69	Beneficial
Totality	2.64	Students perceived ChatGPT as beneficial in learning	2.76	Students perceived ChatGPT as beneficial in learning	2.73	0.73	Students perceived ChatGPT as beneficial in learning

Note. WM: Weighted mean; D: Description; SD: Standard deviation; Weighted mean intervals: 3.26-4.00 (strongly agree: students perceived ChatGPT as highly beneficial in learning); 2.51-3.25 (agree: students perceived ChatGPT as beneficial in learning); 1.76-2.50 (disagree: students perceived ChatGPT as less beneficial in learning); 1.00-1.75 (strongly disagree: students perceived ChatGPT as not beneficial in learning)

Table B4. Perceptions of pre-service teachers on the use of ChatGPT as to mathematics

Indicators	Male		Female		Overall		
	WM	D	WM	D	WM	SD	D
1. I like to use ChatGPT to clarify complex mathematical concepts.	2.50	Less likely to use	2.70	Likely to use	2.66	0.82	Likely to use
2. I like to use ChatGPT to enhance my mathematical skills.	2.30	Less likely to use	2.55	Likely to use	2.49	0.71	Less likely to use
3. I want to use ChatGPT to aid my learning process in mathematics.	2.45	Less likely	2.62	Likely to use	2.58	0.73	Likely to use
Totality	2.42	Less likely to use	2.62	Likely to use	2.58	0.77	Likely to use

Note. WM: Weighted mean; D: Description; SD: Standard deviation; Weighted mean intervals: 3.26-4.00 (strongly agree: students will very likely to use ChatGPT in mathematics); 2.51-3.25 (agree: students will likely to use ChatGPT in mathematics); 1.76-2.50 (disagree: students will less likely to use ChatGPT in mathematics); 1.00-1.75 (strongly disagree: students will unlikely to use ChatGPT in mathematics)

APPENDIX C: INTENTIONS OF MATHEMATICS PRE-SERVICE TEACHERS TO USE ChatGPT

Table C1. Intentions of mathematics pre-service teachers to use ChatGPT in mathematics

Sub-themes	Description	Sample statements
a. ChatGPT as a supplemental learning tool (understanding and comprehension)	The participants intended to use ChatGPT as an essential resource app support for improving their grasp and comprehension of mathematical concepts and lessons. ChatGPT is a resource for enhancing mathematics comprehension by providing explanations and verifying solutions.	<p><i>"I used ChatGPT for me to understand a particular lesson better and also for me to ask for a quick answer."</i>-P7.</p> <p><i>"I used ChatGPT to understand concepts further and explore other alternatives in solving problems."</i>-P12.</p> <p><i>"I rely on ChatGPT to provide a step-by-step procedure and explanations. This approach allows me to deepen my understanding of mathematical processes."</i>-P20.</p>
b. ChatGPT for collaborative problem-solving	ChatGPT supports collaborative problem-solving initiatives by assisting participants in dealing with mathematical problems and enhancing their problem-solving skills through the procedural aid of ChatGPT. Participants appreciate its ability to generate alternative solutions and assist in identifying errors in problem-solving processes.	<p><i>"I can generate ideas about how they did it and another way to solve that problem in a step-by-step manner."</i>-P15.</p> <p><i>"It gives steps or procedures in answering the problem you have which also helps me trace to which part I am mistaken (to where I am wrong)."</i>-P17.</p> <p><i>"I find it beneficial to use ChatGPT after solving problems because it helps to enhance my mathematical skills and reasoning abilities."</i>-20.</p>
c. ChatGPT for advanced mathematics learning	The participant intends to utilize ChatGPT as a flexible resource for mathematics education and application, providing assistance to provide insights into more advanced topics in mathematics, like integral calculus, geometry and investment, logic, abstract algebra, and linear algebra, bridging the gap between fundamental understanding and higher-level learning.	<p><i>"The particular lessons in mathematics that I asked for help with our integral calculus, geometry, and investment."</i>-P2</p> <p><i>"I used ChatGPT, particularly in linear algebra."</i>-P4</p> <p><i>"I have used ChatGPT in mathematics for lessons on proving, especially in modern geometry, analytic geometry, and abstract algebra."</i>-P6</p>
d. ChatGPT for task assistance	This refers to the intention of pre-service teachers to use ChatGPT for assistance in task completion, making it a multifaceted tool that can support a wide range of work. The chatbot can assist the participants through cramming lessons, proving tasks, class reporting, creating assessments, researching, and conducting assignments.	<p><i>"I mostly use it when cramming for my lessons or tasks."</i>-P6</p> <p><i>"I have used it to create assessments, like assessments in learning, where we make test questionnaires. I searched there on ChatGPT for mathematical concepts aligned with this competency."</i>-P13</p> <p><i>"During our research conduct, when provided with a problem to solve, I used ChatGPT for assistance."</i>-P19</p>

APPENDIX D: PERCEIVED CHALLENGES IN USING ChatGPT IN MATHEMATICS LEARNING

Table D1. Pre-service teachers' perceived challenges while using ChatGPT in mathematics learning

Sub-themes	Description	Sample statements
a. Input and interface challenges	This refers to the varying difficulties encountered by the participants when interacting with ChatGPT, including the inability to input or receive visual aids like diagrams or examples, especially for areas that benefit from visual representations. Inputting complex mathematical expressions accurately can be inconvenient, leading to potential misunderstandings. Unclear, ambiguous, or incorrectly phrased prompts can result in irrelevant or incorrect responses. The complex language used by ChatGPT may be difficult for some users to understand, requiring good prompting skills to simplify interactions. All of the said instances hinder effective communication with ChatGPT.	<p><i>"ChatGPT cannot generate or present pictures such as examples [to illustrate trigonometric problems] as this only provides merely textual responses. With this, you could not understand as you will only see texts without visual representations."</i>-P1</p> <p><i>"Sometimes, it's difficult to type mathematical expressions. If you're using a cellphone, it's challenging to input expressions such as exponents or whatever else that may cause ChatGPT to misunderstand my questions, leading to incorrect answers or ChatGPT saying, 'I don't know the answer.'"</i>-P3</p> <p><i>"Sometimes it's confusing because the words used are profound. So, I think the challenge lies in the difficult words provided or complex definitions ..."</i>-P5</p>
b. Dependency and reliance on ChatGPT	This refers to how individuals rely on ChatGPT for information and solutions. It encompasses both the tendency of users to excessively depend on ChatGPT and the potential over-reliance on it that may hinder users' development of independent thinking skills. For instance, users may lean heavily on ChatGPT, like cheating during an exam, which prevents them from relying on their abilities.	<p><i>"Sometimes, there's an overreliance on ChatGPT for all my answers and actions, leading to dependency solely on its capabilities, not mine. This reliance can prevent me from relying on my skills, as ChatGPT becomes the primary source for everything."</i>-P18</p> <p><i>"Another is that because of ChatGPT; I'm not attentive in listening to my instructor because I can understand more in ChatGPT than some of those instructors ... Sometimes our instructor provides equations and answers, but when it comes to ChatGPT, the answers are inaccurate or not the same."</i>-P19</p>
c. Reliability and accuracy concerns	This refers to concerns with ChatGPT encompassing the inconsistent delivery of factually correct and complete responses across various domains. The learners express apprehension regarding the reliability of the information provided by ChatGPT, mainly showing inconsistencies and inaccuracies in reactions. These concerns extend to areas such as mathematics with complex concepts, where users encounter incomplete solutions. Doubts arise from receiving incorrect answers and the ChatGPT's tendency to acknowledge mistakes after users point them out. It also presents learners questioning ChatGPT's reliability in providing accurate information, leading to uncertainty and a lack of trust in its responses.	<p><i>"I don't usually use ChatGPT because of its inconsistent (unreliable) responses, making it inaccurate for me."</i>-P1</p> <p><i>"There are instances where the solutions or step-by-step processes generated by ChatGPT are incomplete or presented in a shortcut manner. Consequently, I sometimes doubt the accuracy or certainty of the answers provided."</i>-P4</p> <p><i>"I find it very amusing because, for example... when I have an answer, and I want to check to ChatGPT if my answer is correct, then, if I prove that the answer that ChatGPT provided is a mistake and then I can confirm that my answer is indeed correct. I will ask the ChatGPT, 'How about this answer, then I'm amused by its reply like 'Yes, yes, you got it right, I'm sorry, I... I made some mistake.' By that experience, I conclude... ChatGPT is not reliable in solving or in answering mathematics concepts."</i>-P14</p>
d. Misalignment with classroom instruction	Users have faced challenges like mis-aligning teachers' answers, processes, and discussions when utilizing ChatGPT. Misalignment refers to the mismatch or lack of synchronization between the information provided by ChatGPT and the expectations, explanations, and interactions within the class-room led by teachers.	<p><i>"Also, my teachers' methods differ from ChatGPT because ChatGPT simplifies my questions. It's not the same as what the teacher teaches. Sometimes, it will generate correct answers, but the process is different."</i>-P10</p> <p><i>"Perhaps the process and the answers provided by ChatGPT are different, and the solutions that it will present are different compared to the teachers and the books."</i>-P14</p>
e. Technical and connectivity issues	This refers to the issues participants faced with ChatGPT, including slow internet connections, system errors, and instability, which led to delays in responses, website collapses, and unresponsiveness.	<p><i>"ChatGPT runs slowly because of an intermittent internet connection. There were also times when system errors occurred."</i>-P2</p> <p><i>"Sometimes, ChatGPT may not be immediately available when you have unstable internet connectivity, especially in environments like our school where internet stability is an issue."</i>-P18</p>

APPENDIX E: PERCEIVED BENEFITS OF USING ChatGPT IN MATHEMATICS LEARNING

Table E1. Pre-service teachers' perceived benefits of using ChatGPT in mathematics learning

Sub-themes	Description	Sample statements
a. Enhanced efficiency in learning and task completion	This refers to how ChatGPT facilitates faster learning and task completion, including its perceived accessibility, convenience, and ease of use. This enables users to benefit from immediate task completion and efficient learning. Whether seeking quick responses, assistance, or ideas, ChatGPT is available 24/7, accessible via various devices, and user-friendly. Its multilingual capability further enhances accessibility, while its quick response time ensures task accomplishment efficiency.	<p>"We can benefit from it by accomplishing our tasks immediately, consuming less time. We can also easily learn with it as it provides ideas ..."-P2</p> <p>"I would say that ChatGPT is very convenient because you don't need to - for example, not all math subjects provide textbooks. So, if there are terms you need to understand the discussion on math topics quickly, it's easy to search for them and understand the lesson."-P5</p> <p>"It can make work easy and time efficient, it can be used as a learning tool with its step-by-step process feature, and it can also be used as a teacher because you can ask if your answers are correct or not and provide reasons why your answers are correct or not."-P8</p> <p>"It is easily accessible via the website, accessible on both phones and computers and very user-friendly. It is available 24/7 as long as you have an internet connection. It can understand multiple languages, including vernacular ones."-P6</p>
b. Enhanced cognitive presence through ChatGPT assistance	Cognitive presence is the active engagement of learners in meaningful interactions and critical thinking processes. ChatGPT assists learners in evaluating their understanding by verifying answers, checking solutions, and exploring alternative problem-solving methods.	<p>"It can widen your knowledge about a particular subject or topic of what you've asked and you can also understand it much better."-P9</p> <p>"It is beneficial for me because it helped me understand better how to properly get the equations that I'm confused about because it provides the process on how to get it. It is also one of the reasons I get to enhance my skills in mathematics."-P10</p> <p>"ChatGPT helps me check the correct answer on the problems to which I've doubted the answers ..."-P17</p> <p>"... I can find out where I'm struggling because I compared my answer with what it provides ..."-P16</p>

APPENDIX F: PROMPTING METHODS

Table F1. Pre-service teachers' prompting methods

Sub-themes	Description	Sample statements
a. Direct input and copying	A prompting method where users directly copy and input questions, information, phrases, or commands to ChatGPT. Users provide clear and straightforward input without relying on any pre-existing context or previous conversation. This ensures that the idea of the question will be constant to meet the expected response.	<p><i>"I just directly copy and input the questions given to us. This is because I feel like the idea will be changed, knowing how sensitive ChatGPT is. I feel like changing even a word could change the substance of the question, consequently changing the understanding of ChatGPT to the question."</i>-P1</p> <p><i>"I directly input the given problems and situations in ChatGPT ... What is given is what I directly copy and paste in ChatGPT."</i>-P2</p>
b. Specific prompt construction	This refers to constructing prompts in a specific manner. This includes formulating questions or statements to guide ChatGPT towards the desired response. This technique involves carefully selecting words, structuring sentences, and including relevant details that provide clear direction to ChatGPT, enabling it to understand and fulfill the user's intent more accurately. Effective specified prompts frequently result in more exact, relevant, and beneficial replies since they better understand what is being looked for.	<p><i>"I construct prompts very specifically, ensuring I ask specific questions to receive precise answers."</i>-P6</p> <p><i>"I break down everything and specify exactly what I'm looking for because ChatGPT usually provides general information. So, you need to specify your question to get a specific answer from it."</i>-P13</p> <p><i>"I typically frame my questions just like what or how or in a specific manner to cater to my learning style. I even ask for step-by-step explanations on arriving at a particular answer using the principles taught in a specific lesson."</i>-P20</p>
c. Response-based prompt adjustment	This refers to adjusting or modifying the initial prompt based on the generated response. This technique allows the user to gain more accurate and relevant responses by asking follow-up questions or providing additional details and instructions in subsequent prompts. The iterative process of adjusting prompts makes the most of ChatGPT's chatting abilities. It helps users adapt and customize the answers they get to match their preferences.	<p><i>"If I'm not satisfied with the responses it provides to that initial prompt, I'll create my own prompts to get the responses I want."</i>-P3</p> <p><i>"I'll craft my questions that steer the conversation towards various sub-topics relevant to my original problem and then connect the responses I receive ... I'll break it down into smaller questions and link the responses accordingly."</i>-P3</p> <p><i>"ChatGPT provides lengthy definitions, so you might need to message back asking for a simpler, more concise response."</i>-P5</p>