



Enhancing Pre-Service Mathematics Teachers' Conceptual Understanding Through Technology Integration: A Systematic Literature Review

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Abstract

This systematic review analyzes the role of technology integration in improving the conceptual understanding of pre-service mathematics teachers based on the latest literature (2016–2025). Current research remains limited in addressing how technology is integrated into pre-service teacher training, with the majority of previous studies focusing instead on technology use among students. This study aims to explore the types of technology utilized in pre-service teacher education and to analyze their influence on the development of pre-service teachers' conceptual understanding. The implementation method followed the PRISMA guidelines with a systematic search in six databases (Scopus, ERIC, ProQuest, Emerald, Taylor & Francis, Springer), resulting in 17 articles that met the inclusion criteria after going through a rigorous selection. The results of the study reveal two key mechanisms: (1) Dynamic visualization and representation (through dynamic geometry software such as GeoGebra) that transforms abstract concepts into concrete, facilitating the understanding of mathematical principles and the relationships between concepts; (2) Interactive learning (Web 2.0-based) that encourages independent exploration, collaboration, and the development of critical thinking. Successful implementation depends on structured guidance within the framework of Technological Pedagogical Content Knowledge (TPACK). The study's conclusions confirm that the integration of technology significantly strengthens the conceptual competence of pre-service teachers as the foundation of effective teaching practices while addressing the gap in previous training models.

Keywords: *Conceptual Understanding; Technology in Education; Pre-Service Teacher*

Introduction

The rapid development of technology marks fundamental changes in various aspects of human life in the 21st century. Technology today has been integrated into almost all aspects of life, including the field of education. Education as the main foundation in creating a modern society plays an important role in preparing skilled individuals who are able to adapt to the rapid development of the world (Güven & Cabakcor, 2013; Imam & Singh, 2015). The use of technology in the field of education, especially in mathematics learning, contributes significantly to supporting the mastery of various mathematical skills needed in the future. One of the essential abilities that can be strengthened through technology is a deep conceptual understanding.

Concept comprehension can not only be defined as understanding a concept by memorization, but more deeply, concept comprehension is a process that involves the construction of mental representations of

information (Greeno, 1978). Conceptual understanding includes understanding the principles of a domain, as well as the relationship between the various concepts in the material. Conceptual knowledge involves not only understanding the facts or procedures in a material, but also about how those facts and procedures are interrelated. This allows learners to understand the broader relationship of a wide range of information (Rittle-Johnson et al., 2001). Conceptual understanding plays a crucial role in the development of a wide range of cognitive abilities, including mathematical reasoning, problem-solving skills, mathematical literacy, critical thinking, and other cognitive aspects.

By increasing the demands in the field of education, the integration of technology in learning becomes crucial, especially in improving the conceptual understanding of a material. The use of technology in teacher education helps pre-service teachers (PSTs) master abstract mathematics materials through various available printed features or tools. Teachers' professional competence, including pedagogical and psychological knowledge, is a significant predictor for the quality of teaching and student achievement in mathematics (Hollenstein & Brühwiler, 2024; König et al., 2021). Teachers with strong conceptual understanding are better able to design and implement learning strategies that support student understanding, for example through problem-based learning or technology integration (Ncube & Luneta, 2025). Professional training and development focused on conceptual understanding can enhance teachers' pedagogical knowledge and their ability to teach mathematics effectively (Bani Irshid et al., 2023; Kilic, 2018).

Research on integrating technology to enhance the comprehension of mathematical concepts among pre-service teachers (PSTs) remains relatively limited. Although the use of technology for conceptual comprehension has been researched, there is no specific technology integration model for the training of pre-service mathematics teachers. Current studies are more focused on the use of technology to improve the ability to understand concepts in school students. For example, a study by Ragab et al. (2024) and Schuetz et al. (2018) proved that technology increases active student participation but still focuses on the level of school students. However, the study by Butcher (2024) explores conceptual change through technology but is limited to the context of general learning, not teacher training. Based on this research gap, the researcher is interested in examining the latest literature development (2016–2025) regarding technology integration strategies in improving the conceptual understanding of PSTs, as well as evaluating empirical evidence related to the impact of various types of technology on specific aspects of PSTs' conceptual understanding.

Methods

This article followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines developed by Moher et al. (2009), to ensure transparency in the execution of the literature review. The article search process was conducted systematically across six reputable scientific databases: Scopus, Taylor & Francis, Emerald Insight, ProQuest, Springer, and ERIC. These databases were chosen due to their rigorous indexing standards and extensive coverage of high-quality publications in the fields of education and educational technology. The detailed search queries applied in each database are presented in Table 1.

The literature search in this study focused on peer-reviewed articles published in English within the field of mathematics education. The inclusion of peer-reviewed articles was intended to ensure the quality and credibility of the studies analyzed. Specifically, the selected articles examined the integration of technology in mathematics learning and its impact on the conceptual understanding of pre-service teachers. Non-empirical publications, such as editorials, book chapters, and conference proceedings, were excluded to prioritize studies supported by systematically verified methodologies. The literature review covered articles published between 2016 and 2025, a time frame chosen to capture the most recent advancements and the relevance of technology integration in enhancing pre-service teachers' conceptual understanding.

The article selection process adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009), following four main stages: (1) identification, (2) screening, (3) eligibility assessment, and (4) inclusion. During the identification stage, the search queries listed in Table 1 were applied across six reputable international databases, yielding a total of 64 articles. After

removing 3 duplicates, 61 articles remained for the screening stage. In this stage, the titles, abstracts, and keywords were examined to evaluate relevance to the study's focus, resulting in articles that potentially met the selection criteria outlined in Table 2. At the eligibility assessment stage, these 35 articles underwent a full-text review to ensure compliance with the predefined inclusion and exclusion criteria. Ultimately, 17 articles satisfied all criteria and were included in the final systematic literature synthesis. A detailed flowchart of the article selection process is presented in Figure 1.

Table 1. Search terms articles

Scopus	(TITLE-ABS-KEY ("technology integration" OR "educational technology" OR "digital tools" OR "ICT") AND TITLE-ABS-KEY ("conceptual understanding") AND TITLE-ABS-KEY ("pre-service teachers" OR "pre-service teachers" OR "future teachers") AND TITLE-ABS-KEY ("mathematics" OR "mathematics education"))
Eric	("technology integration" OR "digital tools" OR "educational technology") AND "conceptual understanding" AND ("pre-service mathematics teachers" OR "pre-service teachers")
Proquest	("technology integration" OR "educational technology" OR "ICT" OR "digital learning") AND ("conceptual understanding") AND ("pre-service mathematics teachers" OR "pre-service teachers") AND ("mathematics education")
Emerald Insight	("technology integration" OR "educational technology" OR "digital tools") AND "conceptual understanding" AND ("pre-service mathematics teachers" OR "teacher candidates")
Taylor Francis	("technology integration" OR "digital tools" OR "educational technology") AND ("conceptual understanding") AND ("pre-service mathematics teachers" OR "future mathematics teachers")
Springer	("technology integration" OR "educational technology" OR "digital tools") AND ("conceptual understanding") AND ("pre-service mathematics teachers" OR "pre-service teachers") AND ("mathematics education")

Table 2. Article Selection Criteria

Inclusion criteria (IC)	Exclusion criteria (EC)
IC1 Studies at all levels of mathematics education	EC1 Studies in disciplines other than mathematics education
IC2 The study focuses on the use of technology mathematics learning.	EC2 Technology is mentioned, but the primary focus is not on enhancing pre-service teachers' conceptual understanding.
IC3 The study reports findings on the impact technology use on pre-service teachers to enhance their conceptual understanding.	EC3 Editorials, books, book chapters, conference papers
IC4 Peer-reviewed article	EC4 Publications in languages other than English.
IC5 Articles published in English	EC5 Articles in the form of systematic literature reviews, meta-analyses, literature reviews, or bibliometric studies.
IC6 Articles published in the 2016–2025-time frame	EC6 Articles indexed in databases other than those defined for the study.
IC7 Articles indexed in Scopus, Taylor & Francis, ProQuest, Emerald Insight, Springer, and ERIC.	EC7 Use of technology unrelated to the conceptual understanding of pre-service teachers.

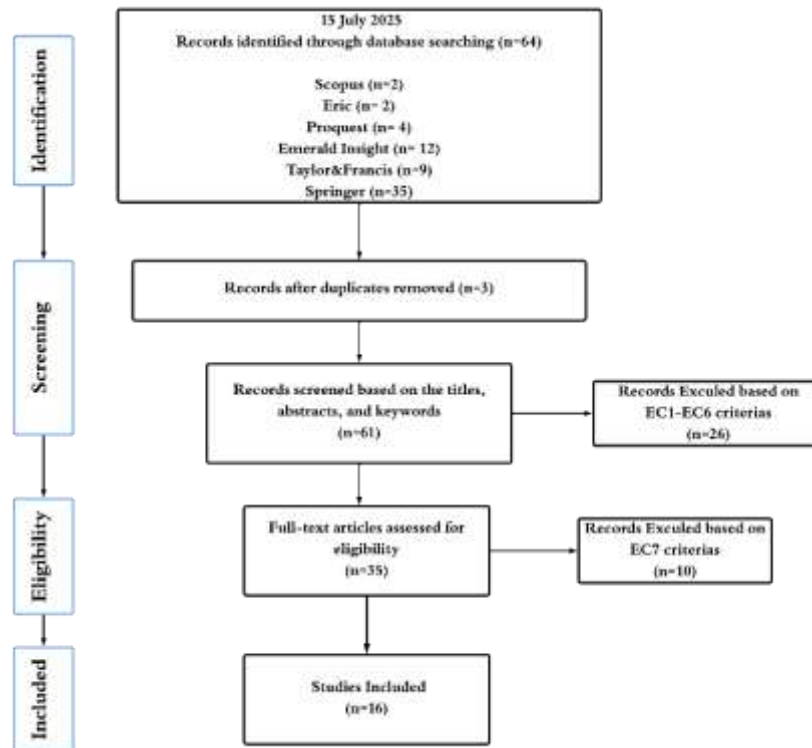


Figure 1. Flow chart of the article's selection process

Result and Discussion

The systematic literature review comprises 17 articles that fulfilled the inclusion criteria and underwent a rigorous evaluation process for subsequent analysis. The detailed findings of the study are presented in Table 3.

Table 3. Data Synthesis Results

No	Study	Number of Samples	Technology Used
1.	(Aidoo et al., 2022)	143	Flipped Classroom
2.	(Awawdeh Shahbani, 2025)	32	GeoGebra and spreadsheets
3.	(Aytekin & Kiymaz, 2019)	4	GeoGebra
4.	(Bullock et al., 2021)	14	GeoGebra
5.	(Dinç & Kim, 2025)	15	block-based programming: Scratch
6.	(Eshetu et al., 2022)	116	Integrated guided inquiry-based learning (TGIBL): GeoGebra
7.	(Geiger, 2014)	22	Web-based online learning modules
8.	(Kutluca, 2017)	120	Computer, interactive whiteboard, projector device, Calculator, Internet
9.	(Lee et al., 2021)	142	Dynamic Ruler
10.	(Patkin & Plaksin, 2019)	16	Geogebra
11.	(Ruqoyyah et al., 2020)	70	Microsoft Excel
12.	(Suparatulorn et al., 2023)	63	GeoGebra
13.	(Tatar & Zengin, 2016)	35	GeoGebra
14.	(Uygun et al., 2023a)	108	Web 2.0
15.	(Villarreal et al., 2018)	108	Internet, spreadsheets, mathematical software programming languages
16.	(Zambak & Tyminski, 2020)	16	Geometer's Sketchpad
17.	(Zambak & Tyminski, 2023)	4	Dynamic geometry software - GSP

Based on the data in table 3, it is found that the integration of technology in mathematics learning has developed, but the integration of technology that is devoted to improving the ability to understand mathematical concepts, especially for pre-service mathematics teachers, is still quite limited. Out of a total of 64 articles, only 17 discuss the use of technology to improve pre-service teachers' conceptual understanding. The collective findings of this review underscore that technology is not merely a supporting tool but a fundamental pedagogical facilitator for prospective teachers. Whether through dynamic visualizations or interactive platforms that foster exploration, technology has consistently been shown to bridge the gap between procedural knowledge and deeper conceptual understanding.

Enhance the Conceptual Understanding of PSTs by Improving Mathematical Visualization and Representation

Findings from the literature consistently indicate that visualization-based technology plays a strategic role in facilitating conceptual understanding, particularly in abstract topics. For pre-service teachers (PSTs), technology not only serves to understand concepts more clearly but also supports the development of more varied, contextual, and interactive representations of material. The use of visual technology in education influences not only students but also prospective teachers. Technology-based visualization plays an important role in improving the conceptual understanding of pre-service teachers by providing a variety of tools and methods that facilitate deeper engagement with learning content. Through dynamic visualization, pre-service teachers be able to connect abstract concepts with real situations, thereby strengthening conceptual understanding. Deeper understanding is an important foundation in designing learning strategies that are appropriate and effective to students' need, especially when teaching complex and abstract material.

Technology also enables the dynamic exploration of mathematical concepts, allowing PSTs to perceive the relationships between abstract ideas and their visual representations. This ability strengthens the mastery of concepts while facilitating the process of generalization and its application in new contexts. Milinković (2024) stated that visualization helps PSTs in understanding and teaching mathematical concepts more effectively. By using visual tools, PSTs can pose and solve problems, thereby enriching their teaching strategies and professional competencies. Twissell (2014) explained that visualization engages mental mechanisms that help learners interact with abstract concepts, making them more concrete and accessible. In line with this, Skulmowski (2023) added that visualizations can simplify complex information, making it easier to process and understand. For instance, realistic visualizations, despite sometimes increasing cognitive load, may aid in retention and transfer of knowledge by emphasizing specific benefits such as depth and shape distinctness.

Among the 17 articles synthesized, seven emphasized that GeoGebra is effective in helping both prospective teachers and students improve their understanding of mathematical concept and develop broader mathematical skills. Supporting this view, Syahidah & Miatun (2024) found that the use of GeoGebra in classroom instruction significantly fosters the development of students' communication skills. Similarly, Tatar & Zengin (2016) report that the use of GeoGebra effectively improves pre-service teachers' understanding of the concept of integral certainty. Through an interactive visualization feature, GeoGebra facilitates the representation of abstract concepts such as Riemann numbers, lower numbers, and upper numbers, thus providing a more concrete learning experience and reducing the tendency for mechanistic memorization-based learning. Similar findings were also reported by Aytekin et al. (2019) and Eshetu et al. (2022), which emphasizes that the integration of GeoGebra in mathematics learning encourages increased conceptual understanding, develops critical thinking skills, and strengthens the ability of pre-service teachers to flexibly connect various mathematical representations.

A strong understanding of concepts helps PSTs master their mathematical skills. Research by Zulu & Mudaly (2023) found that PMTs use mental visualization for simple math problems and symbolic and iconic visualizations for more complex problems. Moreover, the use of diverse visual and symbolic representations has been shown to enhance mathematical creativity alongside conceptual comprehension. Bicer (2021) showed that the group that used visual representations had a greater increase in mathematical creativity than the control group.

Support for PTS's Conceptual Understanding through Interactive Learning

The use of technology provides opportunities for pre-service teachers (PSTs) to optimize active learning through the creation of an interactive, stimulating, and supportive learning environment between pre-service mathematics teacher students. Technology integration allows for more dynamic interactions, both between pre-service teachers and with learning materials, thereby increasing active involvement in the learning process. These findings collectively suggest that visualization-based technologies not only foster deeper conceptual understanding but also play a pivotal role in nurturing higher-order mathematical thinking and creativity among PSTs. Interactive learning with technology encourages active participation and exploration, leading to deeper engagement and understanding of mathematical concepts (Bescherer & Spannagel, 2009; Bos, 2009; Wilkie, 2011). The use of this technology not only supports active learning, but also helps reduce the cognitive burden of pre-service teachers in mastering the material and facilitates the design of teaching resources that are in accordance with the cognitive level of students. For instance, A study by Chen & McPheeters (2012) reported that web-based learning effectively enhances students' understanding of mathematical concepts, particularly in topics like fractions. The interactive features and adaptive capabilities of web-based instruction help meet the diverse needs of students and increase their interest in learning math.

Pre-service teachers show a strong intention to use Web 2.0 tools in a planned manner in future learning to connect various material concepts in a more contextual way. In addition to Web 2.0, Dynamic Geometry Software (DGS) technology, such as The Geometer's SketchPad (GSP), has also proven to be effective in improving mastery of mathematical concepts through more active, exploratory, and interactive learning. Zambak & Tyminski (2017) affirmed that DGS has an important role to play in supporting the development of Specialized Content Knowledge (SCK) PSTs, especially when supported by a positive belief in the potential of technology to deepen understanding of mathematical concepts. With DGS, PSTs can dynamically explore, manipulate, and test geometric concepts that are difficult to do with paper and pencil alone, making their understanding of geometric concepts and procedures more comprehensive.

However, in order for technology integration to run effectively, pre-service teachers need appropriate guidance in combining technology, pedagogy, and content knowledge (TPACK). Without such guidance, the use of technology has the potential to be less than optimal and unable to maintain or improve the cognitive demands of learning. Uygun et al. (2023b) report similar study results showing that the application of technology through the use of Web 2.0 tools, if guided by structured instructional designs such as Hypothetical Learning Trajectory (HLT), has a positive impact on improving the knowledge, skills, and attitudes of pre-service teachers in integrating technology into mathematics teaching, thereby contributing significantly to the development of their TPACK competencies.

Conclusion

Based on a systematic review of the current literature (2016–2025), it can be concluded that technology integration significantly improves the conceptual understanding of pre-service mathematics teachers (PSTs) through two main mechanisms: (1) Dynamic Visualization and Representation, which transforms abstract concepts into concrete through tools such as dynamic geometry software, facilitating an in-depth understanding of mathematical principles and the relationships between concepts; and (2) Interactive Learning based on digital platforms (such as Web 2.0) that create a collaborative environment for self-exploration, critical thinking skill development, and mathematical creativity. The success of this implementation relies heavily on structured pedagogical-technological guidance (TPACK) to ensure optimal cognitive allocation and meaningful learning design. These findings address the gap in previous research by providing a specific model of technology-based training for pre-service teachers, while affirming the strategic role of technology in building the conceptual competencies of pre-service teachers as the foundation of effective teaching practices in the future.

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