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Pedagogical Approaches to the Learning of Mathematical Concepts at the Pre-Tertiary Level

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Abstract

This study examined pedagogical approaches to the learning of mathematical concepts at the pre-tertiary level with the aim of identifying effective instructional strategies, challenges affecting mathematics teaching and learning, and possible measures for improving students' conceptual understanding and academic achievement. The study adopted a systematic literature review design using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to identify, screen, and synthesize relevant empirical and theoretical studies published between 2018 and 2026. Relevant literature was retrieved from databases including Scopus, Google Scholar, and ERIC. The review revealed that learner-centered pedagogical approaches such as constructivist teaching, problem-based learning, inquiry-based learning, collaborative learning, Realistic Mathematics Education, ethnomathematics, and technology-integrated instruction significantly improve students' understanding of mathematical concepts, critical thinking, problem-solving skills, and classroom engagement. Six research questions guided this study, and findings showed that technology-supported instruction enhances learners' visualization and motivation in mathematics learning. However, challenges such as inadequate teacher preparation, poor technological infrastructure, rigid curricula, insufficient instructional materials, and mathematics anxiety continue to hinder effective implementation of innovative pedagogical practices. The study concluded that effective mathematics learning at the pre-tertiary level depends largely on the adoption of learner-centered pedagogies, teachers' pedagogical content knowledge, supportive learning environments, and curriculum reforms that emphasize conceptual understanding and real-life application of mathematical knowledge. The study recommended continuous professional development for teachers, increased technological investment, curriculum restructuring, and the promotion of inclusive and culturally responsive instructional practices to improve mathematics education outcomes.

Keywords: Pedagogical Approaches, Mathematical Concepts, Pre-Tertiary Education, Mathematics Learning, Constructivist Teaching, Problem-Based Learning, Technology Integration.

Introduction

Mathematics is universally recognized as one of the foundational disciplines in education because it contributes significantly to the intellectual, scientific, technological, and socio-economic development of individuals and societies. At the pre-tertiary level, mathematics equips learners with critical thinking, logical reasoning, quantitative literacy, and problem-solving skills necessary for everyday life and future academic pursuits. The learning of mathematical concepts during the formative years of education plays a crucial role in preparing students for advanced studies in science, technology, engineering, and mathematics (STEM)-related fields. Consequently, many educational systems across the world consider mathematics a compulsory subject at the primary and secondary school levels due to its importance in national development and global competitiveness (Jojo, 2019). The learning of mathematical concepts involves more than the memorization of formulas and computational procedures. It requires students to develop conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition toward mathematics. Koskinen & Pitkäniemi (2022) opined that effective mathematics learning occurs when students understand the relationships between mathematical ideas and can apply them meaningfully in different contexts. However, studies have shown that many students at the pre-tertiary level experience persistent difficulties in understanding mathematical concepts such as algebra, geometry, fractions, probability, and trigonometry due to ineffective instructional methods and poor learning experiences. Globally, concerns about students' poor performance in mathematics have continued to attract the attention of researchers, educators, and policymakers. International assessment reports such as the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) consistently reveal disparities in students' mathematical achievement across countries and regions. Many developing countries, particularly in Africa, continue to record low achievement levels in mathematics due to factors such as inadequate instructional resources, poor teacher preparation, overcrowded classrooms, and ineffective pedagogical practices (Graham 2023). In Nigeria and several other sub-Saharan African countries, students' poor performance in external examinations such as WAEC and NECO has raised concerns about the quality of mathematics teaching and learning at the pre-tertiary level (WAEC Chief Examiners' Report, 2023).

One major factor influencing students' understanding of mathematics is the pedagogical approach adopted by teachers during instruction. Pedagogical approaches refer to the methods, strategies, and practices teachers use to facilitate learning and enhance students' understanding of concepts. Traditional teacher-centered approaches, which emphasize rote memorization, repetitive drills, and passive learning, have been criticized for limiting students' conceptual understanding and creativity in mathematics. Such methods often focus on procedural competence rather than deep understanding, thereby making mathematics appear abstract, difficult, and disconnected from real-life experiences (Aliyevna, 2025). The use of concrete-representational-abstract instructional strategy (CRA) and explicit instructional strategy (EIS) will contribute to effective learning of mathematical concepts (Akinoso, 2016, Ogunleye & Akinoso, 2016). In response to the limitations of traditional teaching methods, contemporary mathematics education has increasingly emphasized learner-centered pedagogies that actively engage students in the learning process. Constructivist learning theories proposed by scholars such as Jean Piaget and Lev Vygotsky advocate that learners construct knowledge actively through interaction, exploration, and social engagement. Within mathematics classrooms, constructivist pedagogy encourages inquiry-based learning, collaborative problem-solving, discussion, and hands-on activities that enable learners to

develop meaningful understanding of mathematical concepts (Piaget, 1973; Vygotsky, 1978). Research indicates that learner-centered approaches improve students' engagement, confidence, and achievement in mathematics (Zahedi, et al, 2023). Among the innovative pedagogical approaches currently gaining attention in mathematics education are problem-based learning, collaborative learning, discovery learning, inquiry-based learning, Realistic Mathematics Education (RME), ethnomathematics, and differentiated instruction. Problem-based learning encourages students to solve authentic and contextual mathematical problems collaboratively, thereby promoting critical thinking and analytical reasoning. Similarly, Realistic Mathematics Education emphasizes the connection between mathematics and students' real-life experiences to make abstract concepts more meaningful and understandable (Van den Heuvel-Panhuizen & Drijvers, 2020). These approaches have been found to improve students' conceptual understanding, retention, and mathematical reasoning skills.

The integration of technology into mathematics teaching and learning has also transformed pedagogical practices at the pre-tertiary level (Akinoso, Agoro & Alabi, 2020). Educational technologies such as interactive whiteboards, graphing calculators, dynamic geometry software, learning management systems, virtual manipulatives, and artificial intelligence-based applications have enhanced visualization, interaction, and engagement in mathematics classrooms. Technology-supported instruction enables students to explore mathematical ideas dynamically and interactively, thereby improving conceptual understanding and motivation toward mathematics learning (Yıldırım, 2025). Furthermore, online learning platforms and digital resources have expanded access to mathematics education beyond the traditional classroom environment. Despite the growing recognition of innovative pedagogical approaches, several challenges continue to hinder effective mathematics teaching and learning at the pre-tertiary level. In many developing countries, inadequate teacher training, insufficient instructional materials, poor technological infrastructure, large class sizes, and rigid curricula limit teachers' ability to implement learner-centered instructional strategies effectively. Many teachers still rely heavily on conventional lecture methods due to lack of professional development opportunities and limited pedagogical content knowledge (PCK) required for effective mathematics instruction (Shulman, 1987). Pedagogical content knowledge refers to teachers' ability to transform subject matter into forms that are understandable and accessible to learners.

Additionally, students' attitudes, beliefs, and emotions toward mathematics significantly influence their learning experiences and achievement. Mathematics anxiety, fear of failure, low self-confidence, and negative societal perceptions about mathematics often discourage students from actively participating in mathematics learning activities. Research has shown that students who develop positive attitudes toward mathematics are more likely to engage meaningfully in classroom activities and perform better academically (Irvine, 2020). Therefore, pedagogical approaches that create supportive, inclusive, and motivating learning environments are essential for improving students' interest and achievement in mathematics.

Cultural and socio-economic factors also play significant roles in shaping mathematics learning outcomes at the pre-tertiary level. Learners from disadvantaged backgrounds may experience limited access to quality educational resources, parental support, and conducive learning environments. In multilingual societies, language barriers can further complicate students' understanding of mathematical concepts, especially when the language of instruction differs from students' native languages (Adedeji, 2020). Consequently, culturally responsive pedagogies that recognize learners' backgrounds, experiences, and cultural contexts have become increasingly important in mathematics education (Abdulrahim & Orosco, 2020). Curriculum reforms in

mathematics education have similarly emphasized the need for pedagogical transformation to meet the demands of the twenty-first century. Modern mathematics curricula advocate the development of critical thinking, creativity, communication, collaboration, and digital literacy skills alongside mathematical competence (Sujatha & Vinayakan, 2022). Educational reforms across many countries now encourage competency-based and activity-oriented instructional approaches aimed at preparing students for global challenges and workforce demands. However, the successful implementation of these reforms depends largely on teachers' instructional practices and their willingness to adopt innovative pedagogical methods. Given the persistent challenges associated with mathematics learning and the increasing demand for quality mathematics education, there is a need to critically examine pedagogical approaches that support effective learning of mathematical concepts at the pre-tertiary level. Understanding how different instructional strategies influence students' conceptual understanding, engagement, motivation, and achievement is essential for improving mathematics teaching practices and educational outcomes. Therefore, this study seeks to explore pedagogical approaches to the learning of mathematical concepts at the pre-tertiary level with the aim of identifying effective instructional practices, existing challenges, and possible strategies for enhancing mathematics education.

Literature Review

Concept of Pedagogical Approaches in Mathematics Education

Pedagogical approaches refer to the instructional methods, teaching strategies, classroom practices, and learning activities employed by teachers to facilitate students' understanding of concepts and skills. In mathematics education, pedagogical approaches determine how mathematical knowledge is presented, explored, and internalized by learners. Effective pedagogy in mathematics goes beyond content delivery to include strategies that promote conceptual understanding, reasoning, critical thinking, communication, and problem-solving abilities among learners. Contemporary mathematics education emphasizes learner-centered and activity-based pedagogies that encourage students to actively participate in constructing mathematical knowledge rather than passively receiving information from teachers (Bandewar, 2025). Recent systematic reviews in mathematics education further indicate that innovative pedagogical models such as inquiry-based learning, constructivism, ethnomathematics, and blended learning are increasingly shaping mathematics classrooms globally. Mathematics learning at the pre-tertiary level is particularly important because it forms the foundation for future academic achievement and participation in STEM-related disciplines. However, many students continue to experience difficulties in understanding mathematical concepts due to abstract instructional approaches, mathematics anxiety, and ineffective classroom practices. Researchers argue that the quality of pedagogy adopted by teachers significantly influences students' engagement, motivation, and achievement in mathematics. Effective pedagogical approaches enable learners to connect mathematical ideas with real-life experiences and apply knowledge meaningfully in different contexts (Sujatha & Vinayakan, 2023).

Theoretical Foundations of Mathematics Pedagogy

Constructivist Theory

Constructivist theory is one of the most influential theoretical foundations underpinning modern mathematics pedagogy. The theory, associated with Jean Piaget and Lev Vygotsky, posits that

learners actively construct knowledge through interaction with their environment and social experiences. In mathematics classrooms, constructivist pedagogy encourages students to explore mathematical ideas, engage in collaborative activities, solve problems, and reflect on their understanding. Teachers serve as facilitators who guide students toward conceptual understanding rather than merely transmitting information (Vygotsky, 1978; Mascolo, 2009). Studies have shown that constructivist approaches positively influence students' mathematical reasoning, conceptual understanding, and problem-solving abilities. A recent review on constructivist teaching in mathematics revealed that inquiry-based learning, collaborative discourse, and open-ended mathematical tasks enhance students' comprehension and critical thinking skills. However, some scholars argue that excessive reliance on unguided constructivist learning may overload students cognitively, especially when learners lack sufficient prior knowledge. Cognitive Load Theory therefore suggests the need for guided instruction and scaffolding within constructivist environments to optimize mathematical learning.

Problem-Based Learning in Mathematics

Problem-Based Learning (PBL) is a learner-centered pedagogical approach that uses real-life and contextual problems as the basis for learning. In mathematics education, PBL requires students to investigate mathematical problems collaboratively, formulate solutions, and justify their reasoning processes. This approach emphasizes inquiry, critical thinking, creativity, and application of mathematical knowledge to authentic situations. Research evidence strongly supports the effectiveness of PBL in mathematics education. A systematic review of PBL in K–12 mathematics education found that PBL significantly improves students' conceptual understanding, mathematical reasoning, and problem-solving skills. The review further revealed that geometry and algebra are among the mathematical domains most effectively taught through PBL because they lend themselves naturally to visualization and contextual exploration (Tawfik, et al, 2021). Similarly, another systematic literature review reported that PBL positively affects both cognitive and affective dimensions of mathematics learning. Students exposed to PBL demonstrated improved mathematical understanding, motivation, self-efficacy, and communication skills. These findings suggest that PBL creates interactive and engaging learning environments that enhance learners' confidence and participation in mathematics classrooms. Despite its benefits, the successful implementation of PBL depends largely on teacher competence, classroom management, and availability of instructional resources. Teachers often face challenges such as limited instructional time, inadequate training, and difficulties in designing authentic mathematical problems suitable for students' cognitive levels (Schoenfeld, 2022).

Inquiry-Based Learning in Mathematics

Inquiry-Based Learning (IBL) is another learner-centered pedagogical approach that encourages students to investigate mathematical ideas through questioning, exploration, experimentation, and discovery. Inquiry-based mathematics classrooms allow learners to formulate hypotheses, test mathematical relationships, and develop independent reasoning skills. The approach promotes active engagement and deeper conceptual understanding because students learn mathematics through investigation rather than memorization. Researchers have emphasized that inquiry-based instruction improves students' mathematical thinking and encourages meaningful participation in classroom activities. Inquiry approaches align with the goals of twenty-first-century education, which emphasize creativity, collaboration, communication, and critical thinking skills (Thornhill-Miller, et al, 2023). However, debates continue regarding the effectiveness of pure inquiry

approaches in mathematics education. Some studies argue that minimally guided inquiry may not adequately support learners who possess weak prior knowledge or low mathematical readiness. Consequently, scholars recommend guided inquiry models where teachers provide scaffolding and structured support while allowing students opportunities for exploration and independent reasoning.

Collaborative Learning in Mathematics Education

Collaborative learning involves students working together in groups to solve problems, discuss ideas, and construct knowledge collectively. Mathematics education researchers argue that collaborative interactions help students clarify misconceptions, improve communication skills, and develop deeper understanding of mathematical concepts. Through peer discussions and teamwork, learners are exposed to multiple perspectives and reasoning strategies that enhance conceptual development. Awofala & Lawani (2020b) findings indicate that collaborative or cooperative learning improves students' mathematical achievement and attitudes toward mathematics. Constructivist learning environments that incorporate group discussions, peer tutoring, and cooperative problem-solving activities have been found to increase learners' confidence and participation in mathematics classrooms (Lawal & Awofala, 2021; Awofala & Agbolade, 2023). Additionally, collaborative learning supports social interaction and communication, which are essential components of effective mathematics learning according to Vygotsky's social constructivist theory. Nonetheless, successful collaborative learning requires effective classroom organization and teacher facilitation. In overcrowded classrooms, teachers may experience difficulties monitoring group activities and ensuring equal participation among learners. Differences in students' abilities and interpersonal relationships may also affect group dynamics and learning outcomes.

Realistic Mathematics Education (RME)

Van den Heuvel-Panhuizen & Drijvers (2020) explained Realistic Mathematics Education (RME) as a pedagogical approach developed in the Netherlands that emphasizes connecting mathematics learning with real-life situations familiar to students. RME encourages learners to reinvent mathematical concepts through contextual problems and guided exploration. The approach helps students understand the practical relevance of mathematics and reduces the abstract nature of mathematical instruction. Research findings indicate that RME improves students' conceptual understanding and problem-solving abilities because learners relate mathematical concepts to everyday experiences. Studies further reveal that contextual learning environments enhance students' motivation and engagement in mathematics learning activities (Asmara, et al, 2019). RME also supports gradual movement from informal reasoning to formal mathematical understanding, thereby strengthening learners' cognitive development. Despite its strengths, the implementation of RME requires carefully designed instructional materials and teachers with strong pedagogical skills. In some educational contexts, rigid curricula and examination-oriented teaching practices limit opportunities for contextualized mathematics instruction.

Technology-Based Pedagogical Approaches

The integration of technology into mathematics education has transformed pedagogical practices globally. Educational technologies such as dynamic geometry software, graphing tools, simulations, virtual manipulatives, artificial intelligence applications, and online learning platforms provide interactive and visual learning experiences that improve students' conceptual

understanding. Recent studies demonstrate that technology-supported mathematics instruction enhances learners' motivation, participation, and achievement. Technology allows students to visualize abstract mathematical ideas, manipulate variables dynamically, and receive immediate feedback during learning activities. Furthermore, blended learning and Hyflex instructional models have expanded access to mathematics education and promoted flexible learning opportunities, particularly following the COVID-19 pandemic (Mulenga, & Shilongo, 2025). The use of digital tools such as GeoGebra and gamified mathematics applications has also proven effective in improving students' engagement and mathematical reasoning skills (Awofala & Nwoke, 2025). However, technological integration in mathematics education faces several challenges, including inadequate infrastructure, limited internet access, insufficient teacher competence, and unequal access to digital devices, especially in developing countries (Siregar, 2025).

Ethnomathematics and Culturally Responsive Pedagogy

Yanti (2025) defined Ethnomathematics as the incorporation of learners' cultural experiences, indigenous knowledge, and societal practices into mathematics instruction. Culturally responsive pedagogy recognizes that students learn more effectively when instructional practices reflect their cultural identities and lived experiences. In multicultural societies, culturally responsive mathematics teaching promotes inclusiveness, equity, and relevance in learning. Recent literature highlights the growing importance of ethnomathematics in addressing cultural diversity and enhancing students' engagement in mathematics education. Innovative pedagogical models that integrate local cultural practices into mathematics learning have been found to improve students' understanding and appreciation of mathematics. Ethnomathematics also helps learners recognize mathematics as a human activity embedded in cultural and social contexts rather than as an abstract and isolated discipline. However, integrating ethnomathematics into formal curricula may be challenging where teachers lack adequate training or culturally relevant instructional resources. Curriculum policies that prioritize standardized testing may also discourage culturally responsive teaching approaches.

Pedagogical Content Knowledge and Teacher Effectiveness

Effective mathematics pedagogy depends significantly on teachers' Pedagogical Content Knowledge (PCK). PCK refers to teachers' ability to transform mathematical content into forms that learners can understand easily. According to Lee Shulman (1987), teachers require both subject matter knowledge and pedagogical expertise to facilitate meaningful learning experiences. Research indicates that teachers with strong PCK are better able to identify students' misconceptions, explain mathematical concepts clearly, and select appropriate instructional strategies. Teachers' knowledge of learners' cognitive development and learning difficulties significantly influences classroom effectiveness and students' academic achievement. Continuous professional development programs therefore remain essential for improving teachers' pedagogical competence and instructional practices in mathematics education.

Challenges Affecting Pedagogical Approaches in Mathematics

Despite the increasing adoption of innovative pedagogical approaches, several challenges continue to hinder effective mathematics teaching and learning at the pre-tertiary level. Common challenges include inadequate teacher preparation, overcrowded classrooms, limited instructional resources, rigid curricula, poor technological infrastructure, and examination-oriented teaching practices. In

many developing countries, mathematics instruction remains dominated by teacher-centered methods that emphasize rote memorization and procedural learning. Mathematics anxiety and negative attitudes toward mathematics also affect students' participation and achievement. Learners who perceive mathematics as difficult or intimidating are less likely to engage actively in classroom activities. Additionally, socio-economic disparities influence access to quality mathematics education, technological resources, and supportive learning environments. Furthermore, the transition toward learner-centered pedagogies often requires significant institutional support, teacher training, curriculum reform, and policy commitment. Without these supporting structures, the implementation of innovative pedagogical practices may remain inconsistent and ineffective.

Summary of Literature Gap

The reviewed literature demonstrates that pedagogical approaches such as constructivism, problem-based learning, inquiry-based learning, collaborative learning, Realistic Mathematics Education, technology-supported instruction, and ethnomathematics positively influence students' understanding of mathematical concepts at the pre-tertiary level. However, many studies focus predominantly on isolated pedagogical approaches rather than examining the combined effects of multiple instructional strategies within diverse educational contexts. Additionally, there remains limited research on the implementation of innovative pedagogical approaches in low-resource and developing-country settings, particularly in Africa. Many existing studies also emphasize students' achievement outcomes while giving less attention to teachers' preparedness, classroom realities, and contextual challenges affecting pedagogical implementation. Therefore, further research is needed to explore context-sensitive and sustainable pedagogical approaches that can improve mathematics learning outcomes at the pre-tertiary level.

Research Question

This study seeks to examine pedagogical approaches to the learning of mathematical concepts at the pre-tertiary level. Specifically, the study is guided by the following research questions:

1. What pedagogical approaches are commonly used in teaching and learning mathematical concepts at the pre-tertiary level?
2. How do learner-centered pedagogical approaches influence students' conceptual understanding and academic achievement in mathematics?
3. What roles do technology-based instructional strategies play in improving the learning of mathematical concepts at the pre-tertiary level?
4. What challenges affect the implementation of effective pedagogical approaches in mathematics classrooms at the pre-tertiary level?
5. How does teachers' pedagogical content knowledge influence students' learning of mathematical concepts?
6. What strategies can enhance effective mathematics teaching and learning at the pre-tertiary level?

Method

This study adopted a systematic literature review design using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. PRISMA provides a transparent and organized process for identifying, screening, selecting, and synthesizing relevant studies. Relevant literature was retrieved from academic databases including: Scopus, Google Scholar, and ERIC. The following keywords were used: Pedagogical approaches in mathematics education; Learning mathematical concepts; Pre-tertiary mathematics education; Mathematics teaching strategies; Technology in mathematics learning; and Problem-based learning in mathematics. Studies included in the review met the following conditions: Published between 2018 and 2026; focused on mathematics education at the pre-tertiary level; peer-reviewed journal articles; studies written in English; and studies discussing pedagogical approaches and mathematics learning outcomes. Studies were excluded if they: focused on tertiary mathematics education only; were conference abstracts or unpublished dissertations; and did not discuss pedagogy or mathematics learning. The PRISMA process involved four stages:

1. **Identification:** Relevant studies were identified through database searches.
2. **Screening:** Duplicate articles and irrelevant studies were removed.
3. **Eligibility:** Full texts of selected studies were examined.
4. **Inclusion:** Eligible studies were included for final analysis.

   A total of 245 studies were initially identified. After removing duplicates and irrelevant articles, 72 studies remained for eligibility assessment. Finally, 38 studies met the inclusion criteria and were synthesized in the review.

Results and Discussion

The results and discussion of this systematic review are presented according to the research questions guiding the study. The findings were synthesized from selected empirical and theoretical studies on pedagogical approaches to the learning of mathematical concepts at the pre-tertiary level. Major findings emerging from the listed research questions include:

What pedagogical approaches are commonly used in teaching and learning mathematical concepts at the pre-tertiary level?

The findings revealed that several pedagogical approaches are commonly used in mathematics education at the pre-tertiary level. Among the most widely adopted approaches are constructivist teaching, problem-based learning, inquiry-based learning, collaborative learning, Realistic Mathematics Education (RME), ethnomathematics, differentiated instruction, technology-integrated instruction, and formative assessment strategies (Awofala & Olaniyi, 2023; Awofala & Lawani, 2020a). These approaches are largely learner-centred and emphasise active participation, critical thinking, communication, and conceptual understanding rather than rote memorisation and passive learning (Khan, 2024). The review showed that constructivist pedagogy is one of the dominant instructional approaches in contemporary mathematics classrooms. Constructivist teaching encourages learners to actively construct mathematical knowledge through exploration, interaction, reflection, and collaborative activities. Teachers act as facilitators, guiding students toward conceptual understanding through questioning, discussion, and problem-solving tasks. Studies indicated that constructivist mathematics classrooms improve learners' reasoning abilities and encourage independent learning (Piaget, 1973; Vygotsky, 1978; Mascolo, 2009). Problem-Based Learning (PBL) also emerged as a widely used pedagogical approach in mathematics education. The reviewed studies revealed that PBL engages students in collaboratively solving contextualised, real-life mathematical problems. Through PBL, learners develop critical thinking,

analytical reasoning, and problem-solving skills because they are actively involved in investigating and interpreting mathematical situations. PBL was found to increase students' motivation and classroom participation significantly. Inquiry-Based Learning (IBL) was another common pedagogical approach identified in the reviewed studies. Inquiry-oriented mathematics classrooms encourage learners to ask questions, investigate mathematical relationships, formulate hypotheses, and justify their reasoning. The findings showed that inquiry-based instruction promotes deeper conceptual understanding and supports the development of higher-order thinking skills among learners (Lu, et al, 2021).

The review further identified collaborative learning as an effective and frequently used instructional strategy in mathematics education. Collaborative learning involves group discussions, peer tutoring, cooperative problem-solving, and shared learning experiences. Learners working collaboratively demonstrated stronger conceptual understanding and improved communication skills because they exchanged ideas and clarified misconceptions through social interaction (Awofala & Lawani, 2020). Additionally, technology-integrated pedagogies and assessment such as blended learning, computer-assisted instruction, dynamic mathematics software, computer-based testing and virtual manipulatives were increasingly adopted in mathematics classrooms (Awofala & Nwoke, 2025; Awofala & Uwajuwa, 2023; Awofala, 2020). Educational technologies enabled learners to visualize abstract mathematical concepts and interact with mathematical objects dynamically, thereby improving engagement and conceptual understanding (Fokuo, 2023). The review also highlighted the growing importance of ethnomathematics and culturally responsive pedagogies in mathematics education. These approaches integrate learners' cultural experiences, indigenous practices, and social contexts into mathematics instruction to make learning more meaningful and relatable. Ethnomathematics was found to improve students' interest and participation in mathematics learning activities (Garba, 2024).

How do learner-centered pedagogical approaches influence students' conceptual understanding and academic achievement in mathematics?

The findings revealed that learner-centered pedagogical approaches significantly improve students' conceptual understanding and academic achievement in mathematics. Students exposed to learner-centered instructional strategies demonstrated better understanding of mathematical concepts, improved reasoning abilities, and higher academic performance compared to learners taught through traditional teacher-centered approaches (Hokor, & Sedofia, 2021). The review showed that constructivist teaching positively influences conceptual understanding because learners actively participate in constructing mathematical knowledge through inquiry, exploration, and reflection. Students taught through constructivist methods were better able to connect mathematical concepts to prior knowledge and apply them in unfamiliar situations. Constructivist learning environments also enhanced students' confidence and promoted meaningful learning experiences (Vygotsky, 2018). Problem-Based Learning was found to improve learners' mathematical achievement by engaging students in authentic and contextualized problem-solving activities. Learners participating in PBL demonstrated stronger analytical reasoning, creativity, and ability to apply mathematical concepts to real-life situations. The reviewed studies further indicated that PBL increases students' motivation and classroom engagement because learners perceive mathematics as relevant and meaningful (Awofala & Akinoso, 2024).

Inquiry-Based Learning also contributed significantly to students' conceptual understanding and achievement in mathematics. Learners exposed to inquiry-oriented instruction developed stronger

mathematical reasoning and communication skills because they actively investigated mathematical relationships and justified their reasoning processes. Guided inquiry approaches were particularly effective because teachers provided scaffolding and instructional support while allowing learners opportunities for independent exploration. Similarly, collaborative learning approaches improved students' academic achievement and attitudes toward mathematics. Group discussions and cooperative problem-solving activities enabled learners to clarify misconceptions, exchange ideas, and strengthen conceptual understanding through peer interaction. Collaborative learning also reduced mathematics anxiety and improved learners' confidence in solving mathematical problems (Olanrewaju, & Suleiman, 2019). The review further revealed that Realistic Mathematics Education (RME) enhances conceptual understanding by connecting mathematical instruction to real-life experiences. Learners exposed to contextualized mathematics activities demonstrated better comprehension of abstract concepts because they could relate mathematical ideas to familiar situations. RME also improved students' motivation and participation during mathematics lessons (Herman, et al, 2019).

What roles do technology-based instructional strategies play in improving the learning of mathematical concepts at the pre-tertiary level?

The findings demonstrated that technology-based instructional strategies play significant roles in improving the learning of mathematical concepts at the pre-tertiary level. Educational technologies such as GeoGebra, graphing calculators, simulations, virtual manipulatives, learning management systems, and interactive whiteboards improved students' visualization and understanding of abstract mathematical concepts (Akinoso, 2018; Fokuo, 2023; Lawal & Awofala, 2020; Awofala, Oladipo, Akinoso, Arigbabu, & Fatade, 2022). The review revealed that technology integration enhances students' motivation, participation, and engagement during mathematics instruction. Interactive digital tools enabled learners to manipulate mathematical objects dynamically, explore patterns, and receive immediate feedback during learning activities. Consequently, students became more actively involved in mathematics learning and demonstrated improved conceptual understanding. Attard & Holmes (2022) indicate that blended learning and online instructional platforms expanded access to mathematics education beyond the traditional classroom setting. Technology-supported instruction promoted flexible learning opportunities and individualized learning experiences for students with diverse learning needs (Awofala et al., 2021; Awofala, Malasari, Adeniyi, Lawani, & Udeani, 2022). Learners could revisit instructional materials, participate in online discussions, and engage in self-paced learning activities that improved academic performance. However, despite the benefits of technology integration, the findings identified several challenges affecting effective implementation. These included inadequate technological infrastructure, poor internet connectivity, unstable electricity supply, insufficient teacher competence, and unequal access to digital devices, particularly in developing countries. These challenges limited the effectiveness of technology-supported mathematics instruction in many educational settings (Rybak, 2021).

What challenges affect the implementation of effective pedagogical approaches in mathematics classrooms at the pre-tertiary level?

The findings revealed several challenges affecting the implementation of effective pedagogical approaches in mathematics classrooms. One major challenge identified was inadequate teacher preparation and limited pedagogical content knowledge (Akinoso, 2014; Akinoso; 2015; Akinoso, 2017; Awofala & Fatade, 2023). Many teachers lacked sufficient training in learner-centered

instructional methods, formative assessment, and educational technology integration, thereby limiting their ability to implement innovative pedagogical approaches effectively (Mukuka et al., 2019). The review also identified overcrowded classrooms as a major barrier to effective mathematics instruction. Large class sizes limited teachers' ability to provide individualized support, monitor group activities, and facilitate collaborative learning effectively. Consequently, many teachers relied heavily on lecture-based instruction because learner-centered activities became difficult to manage in overcrowded classrooms (Graham, 2023; Arigbabu & Awofala, 2023). Insufficient instructional materials and poor technological infrastructure also emerged as major challenges affecting mathematics pedagogy. Many schools lacked adequate textbooks, manipulatives, computers, internet access, and digital learning resources necessary for effective learner-centered and technology-supported instruction. In developing countries, inadequate funding and infrastructural deficiencies further hindered the successful implementation of innovative teaching approaches. The review further revealed that rigid curricula and examination-oriented educational systems discourage teachers from adopting learner-centered pedagogies. Teachers often focused on syllabus completion and preparation for standardized examinations rather than conceptual understanding and critical thinking development. This limited opportunities for inquiry-based learning, problem-solving activities, and contextualized instruction. It is confirmed that mathematics anxiety and negative attitudes toward mathematics significantly affected students' participation and achievement (Awofala et al., 2024). Learners who perceived mathematics as difficult or intimidating were less likely to engage actively in classroom discussions and problem-solving activities (Awofala, Lawal, Arigbabu, & Fatade, 2022). Socio-economic disparities also contributed to inequalities in access to quality mathematics education and supportive learning environments (Meeran, & Van Wyk, 2022).

How does teachers' pedagogical content knowledge influence students' learning of mathematical concepts?

The findings established that teachers' Pedagogical Content Knowledge (PCK) significantly influences students' learning of mathematical concepts. Teachers with strong PCK demonstrated greater ability to explain mathematical concepts clearly, identify students' misconceptions, and apply appropriate instructional strategies that facilitate conceptual understanding. Effective mathematics teaching, therefore, depends not only on teachers' mastery of subject matter but also on their ability to transform mathematical knowledge into understandable forms for learners (Shulman, 1987). The review further revealed that teachers with strong pedagogical competence create supportive and engaging classroom environments that encourage active participation and meaningful learning. Such teachers effectively integrate instructional resources, questioning techniques, collaborative activities, and formative assessment practices into mathematics lessons to improve students' understanding and achievement (Pinger, et al, 2018; Awofala & Olaniyi, 2023). Additionally, studies reviewed showed that continuous professional development programs positively influence teachers' instructional competence and classroom effectiveness. Teachers who received training in learner-centered pedagogies, educational technology integration, and assessment strategies demonstrated improved confidence and effectiveness in facilitating mathematics learning. Professional development programs therefore remain essential for strengthening mathematics instruction at the pre-tertiary level.

What strategies can enhance effective mathematics teaching and learning at the pre-tertiary level?

The findings revealed several strategies capable of enhancing effective mathematics teaching and learning at the pre-tertiary level. One major strategy identified was the adoption of learner-centered pedagogical approaches such as constructivist teaching, inquiry-based learning, collaborative learning, and problem-based learning. These instructional approaches improve students' conceptual understanding, critical thinking, and engagement in mathematics learning activities (Lee, & Paul, 2023). The review also highlighted the importance of continuous professional development for mathematics teachers. Regular training programs focused on pedagogical content knowledge, instructional technology, classroom management, and assessment practices improve teachers' competence and effectiveness in facilitating mathematics instruction (Stoilescu, 2015). Technology integration was another important strategy identified for improving mathematics learning outcomes (Awofala, Malasari, Adeniyi, Lawani, & Udeani, 2022). Providing schools with adequate technological infrastructure, digital learning tools, and internet access supports interactive and engaging mathematics instruction. Teachers should also receive training on the pedagogical use of educational technologies to maximize learning outcomes (Attard & Holmes, 2022). The findings also showed that supportive and inclusive classroom environments reduce mathematics anxiety and improve students' confidence and participation. Teachers should encourage positive reinforcement, collaborative activities, and culturally responsive teaching practices that recognize learners' backgrounds and experiences. Such strategies improve learners' attitudes toward mathematics and promote equitable participation in classroom activities (Sujatha, & Vinayakan, 2022).

Conclusion

This systematic review examined pedagogical approaches to the learning of mathematical concepts at the pre-tertiary level and established that learner-centered instructional strategies significantly improve students' conceptual understanding, engagement, motivation, and achievement in mathematics. The findings demonstrated that pedagogical approaches such as constructivism, problem-based learning, inquiry-based learning, collaborative learning, Realistic Mathematics Education, ethnomathematics, and technology-supported instruction are more effective in promoting meaningful learning than traditional teacher-centered methods. The review further revealed that effective mathematics instruction depends largely on teachers' pedagogical content knowledge, classroom practices, and ability to create supportive and interactive learning environments. Technology integration and contextualized learning approaches were also found to improve learners' visualization, participation, and application of mathematical concepts in real-life situations. However, the successful implementation of innovative pedagogical approaches remains constrained by challenges such as inadequate teacher preparation, poor technological infrastructure, overcrowded classrooms, and rigid curricula (Agbata et al., 2024). Overall, the study concludes that improving the learning of mathematical concepts at the pre-tertiary level requires comprehensive educational reforms that prioritize learner-centered pedagogy, teacher professional development, curriculum flexibility, technological investment, and supportive learning environments. Effective pedagogical practices are essential for developing students' critical thinking, problem-solving skills, 21st century skills, and mathematical competence necessary for national development and participation in the global knowledge economy (Awofala et al., 2019).

Recommendations

The following recommendations should be considered;

i. Mathematics teachers should adopt learner-centered pedagogical approaches such as problem-based learning, inquiry-based learning, collaborative learning, and constructivist teaching methods to improve students' conceptual understanding and active participation during mathematics instruction.

ii. Governments and educational stakeholders should organize continuous professional development programs aimed at improving teachers' pedagogical content knowledge, instructional competence, and technological skills necessary for effective mathematics teaching.

iii. Schools should invest in technological infrastructure such as computers, internet facilities, digital learning platforms, and interactive instructional software to support technology-integrated mathematics instruction and improve learners' engagement and achievement.

iv. Curriculum developers should design mathematics curricula that emphasize conceptual understanding, creativity, critical thinking, and real-life application of mathematical knowledge rather than rote memorization and examination-oriented instruction

v. Teachers should incorporate formative assessment practices such as classroom questioning, peer assessment, reflective activities, and continuous feedback to identify students' misconceptions and improve learning outcomes effectively.

vi. Teachers should integrate culturally responsive pedagogical practices and ethnomathematical examples into classroom instruction to make mathematics more meaningful, inclusive, and relevant to learners' cultural experiences

vii. Schools and teachers should also create supportive classroom environments that reduce mathematics anxiety through encouragement, positive reinforcement, collaborative activities, and engaging instructional strategies that improve students' confidence and attitudes toward mathematics.

Suggestions for Further Studies

Future studies should investigate the following:

1. The long-term effects of technology-supported pedagogical approaches on students' mathematical achievement, retention, and problem-solving abilities at the pre-tertiary level.
2. Comparative differences in pedagogical practices and mathematics learning outcomes between urban and rural schools across different educational contexts.
3. The relationship between teachers' pedagogical content knowledge and students' mathematical reasoning and achievement in diverse classroom environments.
4. Strategies for reducing mathematics anxiety and improving students' confidence through innovative and inclusive instructional practices.
5. The effectiveness of blended learning, hybrid instruction, and virtual mathematics classrooms in improving conceptual understanding and academic achievement at the pre-tertiary level.

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