
THE ROLE OF ARTIFICIAL INTELLIGENCE AND MULTIMODAL APPROACHES IN ENHANCING LEARNING ENGAGEMENT AND MATHEMATICS CONCEPTUAL UNDERSTANDING AMONG JUNIOR HIGH SCHOOL STUDENTS: A SYSTEMATIC LITERATURE REVIEW

Mariani Manik¹, Phill. I Gusti Putu Sudiarta², I Nengah Suparta³

^{1,2,3} Universitas Pendidikan Ganesha (Undiksha), Bali, Indonesia

e-mail: * marianirekayasa@gmail.com, gussudiarta@undiksha.ac.id, nengah.suparta@undiksha.ac.id

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Abstract

The rapid development of artificial intelligence (AI) and multimodal learning has created new opportunities to improve mathematics education, especially in enhancing junior high school students' engagement and conceptual understanding. Although many studies have explored these approaches, their findings remain scattered. This study conducts a Systematic Literature Review (SLR) to examine trends, implementation characteristics, and the contributions of AI and multimodal learning from 2015 to 2025. Using Publish or Perish (PoP), Scopus, and ERIC, 261 articles were identified, with 30 meeting the inclusion criteria and analyzed using thematic synthesis in Rayyan. The results show that AI integration has progressed from rule-based intelligent tutoring systems to adaptive and generative models that provide rapid feedback, personalize learning paths, and detect misconceptions. Multimodal learning strengthens mathematical understanding through dynamic visualizations, digital manipulatives, gestures, auditory narration, and interactive simulations, supporting cognitive, affective, and behavioral engagement. The combination of AI and multimodal learning yields the strongest effects through hybrid intelligence, merging AI-driven immediate feedback with teacher-led reflection. Overall, both approaches significantly enhance students' engagement and conceptual understanding, though their effectiveness depends on teacher readiness, technological infrastructure, and pedagogical design. The study underscores the need for improved teacher competencies, better school infrastructure, and curricula supporting adaptive learning, alongside further research on long-term multimodal AI integration in low-resource schools.

Keywords: artificial intelligence, multimodal approach, learning engagement, conceptual understanding, systematic literature review.

1. Introduction

The development of mathematics education in the digital era requires learning approaches that not only emphasize procedural proficiency but also strengthen students' conceptual understanding and learning engagement. These two aspects are fundamental in improving learning quality and enabling students to transfer mathematical knowledge to broader and more complex contexts. Conceptual understanding has been widely discussed in mathematics education research, including in the Indonesian context. Previous studies indicate that deep conceptual understanding allows students to think flexibly, construct generalizations, evaluate mathematical arguments, and apply concepts meaningfully in new situations (Parwati et al., 2021; Oktavianiasih et al., 2023). However, empirical evidence shows that many junior high school students in Indonesia still experience difficulties in independently constructing mathematical concepts, largely due to teacher-centered and procedure-oriented instructional practices (Suweken et al., 2017). These conditions often result in weak conceptual representations, persistent misconceptions, and limited ability to connect multiple mathematical representations.

Student engagement is another critical dimension influencing the effectiveness of mathematics learning. Engagement encompasses cognitive, affective, behavioral, social, and metacognitive involvement in learning activities. Research suggests that learning environments encouraging dialogue, exploration, questioning, and reflection significantly enhance students' conceptual understanding (Suweken, 2020; Parwati et al., 2021). Instructional models such as guided discovery learning, TANDUR, SIOP, digital manipulatives, and interactive e-modules have demonstrated positive effects on students' motivation, participation, and depth of interaction with mathematical content (Oktavianiasih et al., 2023; Suweken et al., 2017). Consequently, engagement and conceptual understanding function as mutually reinforcing constructs that should be jointly addressed in the design of junior high school mathematics instruction.

Alongside pedagogical developments, rapid advances in educational technology have introduced new possibilities for enhancing mathematics learning through artificial intelligence (AI) and multimodal approaches. Early applications of AI in education were dominated by rule-based tutoring systems developed in the 1980s and 1990s, which relied on predefined rules and limited response patterns (Otero et al., 2024). Subsequent generations of intelligent tutoring systems incorporated learner modeling, error diagnosis, and adaptive feedback mechanisms, enabling more personalized learning support. In the past decade, breakthroughs in natural language processing, deep learning, and generative AI have significantly expanded these capabilities, allowing systems to respond dialogically, analyze learning interactions holistically, and deliver multimodal feedback that integrates text, visuals, audio, and simulations in ways that increasingly resemble human instructional support (Otero et al., 2024). Recent studies suggest that generative and multimodal AI in mathematics education can strengthen conceptual understanding and learning engagement by

providing adaptive explanations, contextualized problems, and immediate feedback that supports higher-order thinking (Cosentino et al., 2025; Walkington, 2025).

Multimodal learning approaches further contribute to meaningful mathematics learning by enabling students to engage with concepts through multiple representational forms. The integration of dynamic visualizations, simulations, gestures, audio narration, digital manipulatives, and symbolic representations helps bridge abstract mathematical ideas with concrete experiences and supports diverse cognitive pathways (Bush, 2021). When orchestrated effectively, multimodal environments facilitate deeper sense-making and reduce cognitive overload. Artificial intelligence acts as a powerful enabler in this context by adaptively coordinating these modalities, adjusting representations, pacing, and levels of scaffolding according to individual learner needs. Through this integration, AI enhances not only access to multimodal resources but also the precision and responsiveness of instructional support.

Despite the growing body of research on AI and multimodal learning in mathematics education, existing literature reviews tend to examine these approaches separately or focus on specific technologies, educational levels, or learning outcomes. Previous reviews often emphasize technical development, general effectiveness, or higher education contexts, while providing limited synthesis on how AI and multimodal approaches jointly contribute to both learning engagement and conceptual understanding at the junior high school level. Moreover, there remains a lack of comprehensive mapping of implementation characteristics, pedagogical roles, and synergistic mechanisms between AI and multimodal learning across recent empirical studies. As a result, educators and researchers lack an integrated evidence base that clarifies what has been achieved, what remains underexplored, and how these approaches can be effectively designed and implemented in diverse school contexts, including low-resource environments.

Furthermore, the literature consistently highlights the irreplaceable role of teachers in mediating the use of AI and multimodal technologies. Teachers function not only as facilitators of learning but also as guides in conceptual reflection, ethical decision-making, and meaningful interaction, ensuring that technology supports rather than replaces human-centered pedagogy (Suweken et al., 2025). Without adequate teacher readiness and pedagogical alignment, the potential benefits of AI and multimodal approaches may not be fully realized.

Based on these considerations, a Systematic Literature Review (SLR) is necessary to synthesize and critically examine existing research on the integration of artificial intelligence and multimodal approaches in junior high school mathematics learning. This review aims to address gaps in previous studies by systematically mapping research trends, implementation characteristics, and the combined contributions of AI and multimodal learning to students' engagement and conceptual understanding. By doing so, the study seeks to provide a coherent empirical foundation for future instructional design, teacher professional development, and curriculum innovation aligned with the demands of 21st-century mathematics education.

This introduction underscores the importance of conducting a Systematic Literature Review to understand the extent to which artificial intelligence and multimodal approaches can enhance junior high school students' engagement and conceptual understanding in mathematics learning, as well as how the teacher's role may be redefined within an educational ecosystem increasingly

shaped by artificial intelligence. This review is also expected to provide conceptual and empirical foundations for the development of innovative learning media and pedagogical models aligned with 21st-century educational needs.

Based on the urgency of integrating artificial intelligence and multimodal approaches into junior high school mathematics learning, the research questions in this systematic literature study are formulated to map research directions and identify their contributions to improving learning quality. The research questions are stated as four RQs:

Table 1.

Research Questions

Code	Research Question
RQ1	What are the characteristics of artificial intelligence implementation in junior high school mathematics learning?
RQ2	How does artificial intelligence contribute to students' mathematical conceptual understanding?
RQ3	What is the role of multimodal learning in enhancing student engagement in mathematics learning?
RQ4	How do artificial intelligence and multimodal learning synergize to improve students' engagement and conceptual understanding?

2. Methods

This study employs a Systematic Literature Review (SLR) design that follows the principles of transparency and accountability as emphasized in the PRISMA 2020 guidelines. The entire process was conducted systematically through the stages of identification, screening, eligibility assessment, and final inclusion of relevant scholarly sources. The literature search strategy involved the use of the Publish or Perish (PoP) software to optimize article retrieval through Google Scholar, as well as direct searches in the Scopus and ERIC databases to access reputable international publications. Publish or Perish served as the primary tool for extracting metadata, organizing citations, selecting preliminary search results, and ensuring comprehensive coverage of sources.

The search process began by formulating combined keywords that reflected the study's focus, including "artificial intelligence," "AI in education," "multimodal learning," "mathematics learning," "student engagement," and "conceptual understanding," along with specific descriptors such as "middle school," "junior high school," and "lower secondary." The search was limited to publications from 2015–2025 to match the scope of a ten-year review. Search results from Google Scholar via PoP were then merged with those from Scopus and ERIC. All articles from the three sources were exported in RIS/CSV format and uploaded into Rayyan for data management, blind review, and bias reduction during the screening process.

During the identification stage, a total of 261 articles were retrieved from all sources (Google Scholar via PoP, Scopus, and ERIC). Rayyan detected five duplicates, which were removed, leaving 253 articles for screening. Title and abstract screening eliminated 211 articles for lacking relevance to mathematics learning, AI, multimodal learning, or the junior high school context. Forty-two articles were selected for full text retrieval, though 12 could not be accessed and were

thus excluded from further analysis. The remaining 30 accessible articles were evaluated based on thematic relevance, methodology, population, and their contributions to the variables examined. All 30 articles met the eligibility criteria and were included in the thematic synthesis. To maintain consistency in article selection, explicit inclusion and exclusion criteria were established and applied throughout the eligibility assessment. The following table summarizes the criteria used:

Table 2.
Inclusion and Exclusion Criteria

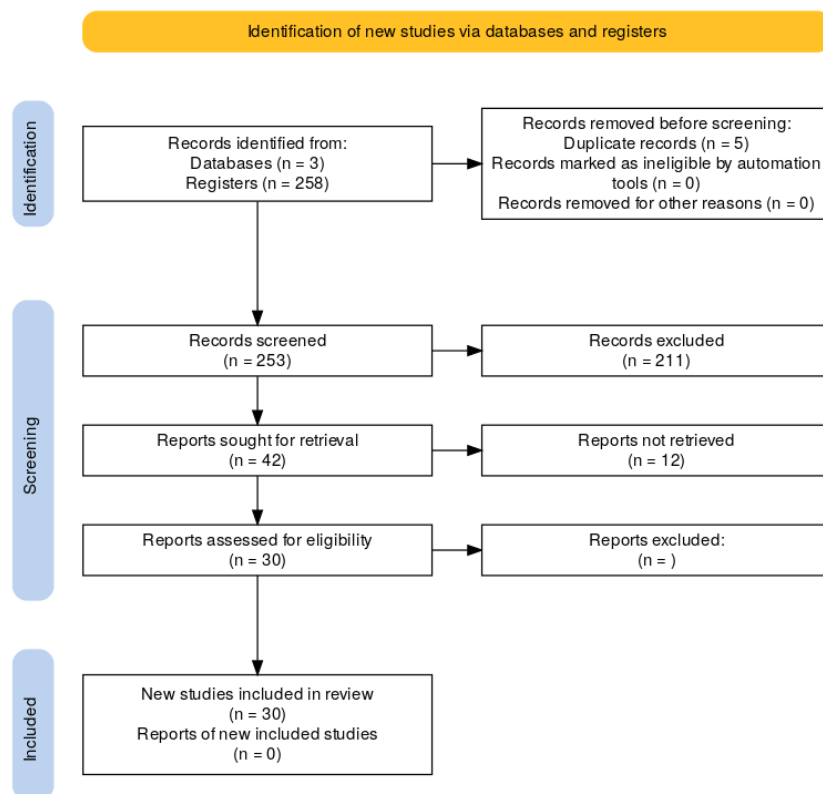
Aspect	Inclusion Criteria	Exclusion Criteria
Publication Year	Articles published between 2015–2025.	Articles published before 2015 or unpublished works (e.g., non-peer-reviewed preprints).
Type of Publication	Peer-reviewed journal articles indexed in Scopus, ERIC, or Google Scholar.	Books, conference proceedings, theses, dissertations, project reports, or non-peer-reviewed articles.
Language	Articles written in English or Indonesian.	Articles written in other languages without an English translation or abstract.
Field of Study	Focus on mathematics education at the middle school/junior high school level.	Studies outside the context of mathematics education (e.g., physics, language, economics).
Technology Context	Studies using or discussing Artificial Intelligence (AI) in learning (e.g., chatbots, intelligent tutoring, adaptive learning, AI-based assessment).	Articles discussing general technology without AI elements (e.g., PowerPoint, videos, basic e-learning).
Learning Approach	Studies employing or examining multimodal approaches (visual, auditory, kinesthetic, digital-interactive).	Studies that do not apply multimodal elements or focus on only a single mode.
Research Focus	Studies examining the effects of AI and/or multimodal approaches on student engagement or mathematical conceptual understanding.	Articles assessing general cognitive outcomes without focusing on engagement or conceptual understanding.
Education Level	Studies conducted at the junior high school level or strongly aligned with junior high learning contexts.	Studies conducted exclusively at the elementary, senior high school, or university level.
Research Design	Quantitative, qualitative, mixed methods, or AI-based learning media development studies.	Editorials, opinion papers, non-systematic reviews, or articles without empirical data.

Aspect	Inclusion Criteria	Exclusion Criteria
Accessibility	Articles available in full text and downloadable for content analysis.	Articles available only as abstracts or inaccessible in full text.

Next, data from the studies that passed the selection process were extracted, including the types of AI technologies or multimodal approaches used, research designs, populations, measurement instruments, and key findings related to engagement or conceptual understanding. The analysis was conducted using a thematic synthesis approach, which included coding, theme categorization, and narrative integration across studies to produce a comprehensive understanding of research trends and their implications for mathematics learning practices at the junior high school level. This approach allows the review results to be not only descriptive but also interpretive, providing directions for theoretical and practical development based on the current research landscape. Before entering the analysis stage, the literature selection process which included identification, screening, eligibility assessment, and final inclusion of studies is briefly presented through a PRISMA diagram.

Figure 1.

Article Selection Flowchart Using PRISMA 2020 (Using screening data from Rayyan)



To provide a comprehensive overview of the characteristics, research focus, and key findings of all the studies analyzed, a summary of the thirty selected articles is presented in the table below. This table contains information on the authors, year of publication, research titles, and core findings that form the basis of the analysis in the results and discussion section.

Table 3.
Systematic Analysis Results of the Selected Studies

No.	Authors (Year)	Title	Key Findings
1	Jailani, Rosli, & Sofwan Mahmud (2025)	<i>Blended Learning and Emerging Technologies in Mathematics Education: A Comprehensive Structured Review</i>	Blended learning and emerging technologies such as AI, VR, and multimodal environments enhance students' enthusiasm, engagement, and mathematical achievement. Effectiveness depends on device availability, teacher readiness, and socioeconomic context. Intensive teacher training and curriculum strengthening are needed. Longitudinal gaps and student diversity remain areas for future research.
2	Cosentino et al. (2025)	<i>Bridging AI and Human Feedback: Hybrid Intelligence in Embodied Math Education</i>	AI feedback (e.g., GPT-4) is efficient for real-time responses and systematic explanations, yet teacher involvement remains crucial. A hybrid model (AI + teacher) produces more inclusive, personalized, and adaptively effective learning experiences.
3	Chinjunthuk, Chaipayut, & Junpeng (2025)	<i>Developing Numbers and Algebra Outcomes Using an Intelligent Tutoring System</i>	Intelligent Tutoring Systems (ITS) with adaptive scaffolding and self-explanation help students understand algebra and number concepts more effectively. Active use of explanatory menus increases autonomy and reflective mathematical thinking.
4	Almoubayyed et al. (2023)	<i>Rewriting Math Word Problems to Improve Learning Outcomes for Emerging Readers</i>	AI-based rewriting of math word problems for early readers reduces misconceptions and accelerates comprehension. Effects are strong for low-reading-ability students, moderate for higher-reading-ability students.
5	Rebolledo-Mendez et al. (2022)	<i>Meta-Affective Behaviour within an Intelligent Tutoring System for Mathematics</i>	Managing negative emotions (frustration, anxiety) within ITS significantly improves achievement and resilience. Affective scaffolding promotes deeper learning.
6	Mohamed et al. (2022)	<i>Artificial Intelligence in Mathematics Education: A Systematic Literature Review</i>	AI supports personalized learning, automated assessment, and instant feedback. However, effectiveness depends on teacher supervision to avoid content errors and bias.

No.	Authors (Year)	Title	Key Findings
7	Arslan & Selek (2025)	<i>ChatGPT's Capabilities and Limitations in Problem Posing</i>	ChatGPT can generate and solve math problems with explanations, but accuracy drops in open-ended or real-world tasks. AI should be used as a thinking partner under teacher supervision.
8	Rzyankina, George, & Simpson (2024)	<i>Enhancing Conceptual Understanding in Engineering Mathematics Through E-Textbooks</i>	Interactive AI-powered e-textbooks strengthen understanding of complex mathematical concepts through visualization and adaptive exercises. Collaboration tools deepen comprehension beyond rote memorization.
9	Yavich (2025)	<i>Improving Learning Outcomes in Advanced Mathematics for Underprepared University Students</i>	Intelligent digital platforms benefit underprepared students through adaptive practice, dynamic visualization, and structured progression.
10	Copur-Gencturk, Li, & Atabas (2024)	<i>Improving Teaching at Scale: Can AI Be Incorporated into Professional Development?</i>	AI accelerates the creation and personalization of teaching resources, but expert teacher review remains essential to prevent misconceptions in math content.
11	Vest et al. (2022)	<i>Self-Explanation of Worked Examples Integrated in an ITS</i>	Self-explanation features significantly strengthen algebra understanding by promoting reflective thinking and enabling students to learn from automated AI feedback.
12	Magat & Sangalang (2024)	<i>Teachers' Familiarity, Perceptions, and Training Needs on the Use of ChatGPT in Mathematics Instruction</i>	Teachers see potential in AI for material development and differentiated assessment, but highlight the need for technical, pedagogical, and policy training.
13	Lademann, Henze, & Becker-Genschow (2025)	<i>Augmenting Learning Environments Using AI Custom Chatbots</i>	AI chatbots reduce cognitive load and increase motivation, comfort, and confidence, although final conceptual exam scores remain comparable to traditional instruction.
14	Lin & Riccomini (2025)	<i>Inclusive Education in Rural Settings</i>	Integration of IPF with free apps (IXL, KUTA, ChatGPT) improves math mastery among students with disabilities in rural areas. Teacher training and community support are vital.
15	Vitale et al. (2025)	<i>Anticipatory Diagrammatic Self-Explanation for Early Algebra</i>	Diagram-based self-explanation accelerates students' transition from concrete to formal algebraic thinking and fosters independent learning.

No.	Authors (Year)	Title	Key Findings
16	Nye et al. (2018)	<i>SKOPE-IT: Natural Language Tutoring on an Adaptive Learning System</i>	Natural language dialog (AutoTutor) increases learning gains by encouraging reflection, exploration, and structured practice.
17	Mandal & Naskar (2021)	<i>Classifying and Solving Arithmetic Math Word Problems—An Intelligent Math Solver</i>	AI algorithms can classify and solve arithmetic word problems, though accuracy drops with complex, multi-step, or context-heavy tasks.
18	Bush (2021)	<i>Software-Based Intervention with Digital Manipulatives</i>	Digital manipulatives effectively improve understanding of fractions and basic geometry, especially when combined with reflective activities and guided reasoning.
19	Bernacki & Walkington (2018)	<i>The Role of Situational Interest in Personalized Learning</i>	AI-driven personalization increases motivation, engagement, and achievement by tailoring content to students' interests and contexts.
20	Rau, Aleven, & Rummel (2017)	<i>Connections among Multiple Graphical Representations of Fractions</i>	Making connections across graphical representations strengthens conceptual understanding and transfer compared to repetitive visual drills.
21	Zhang et al. (2021)	<i>Interaction Patterns in Exploratory Learning Environments</i>	Exploratory AI environments with visualization and tiered feedback enhance understanding but depend on cultural learning norms and student preferences.
22	Changkui (2025)	<i>Applications of Large Multimodal Models in STEM Education</i>	LMMs enable visual explanations, simulations, and cross-format representations, improving comprehension and motivation when access is not limited.
23	Liang et al. (2023)	<i>Exploring the Potential of ChatGPT in Mathematics Education</i>	ChatGPT effectively guides students through steps and hints but can err on multi-step or vector-based problems without teacher oversight.
24	Lee et al. (2023)	<i>Multimodality of AI for Education</i>	Multimodal AI enriches learning through natural, contextual, and interactive communication across modalities, approaching "general intelligence" behavior.
25	Song et al. (2025)	<i>Students' Roles, Opportunities, and Challenges with a Generative AI-Powered Teachable Agent</i>	Students report AI supports autonomous, adaptive, and personalized learning, though reasoning errors and supervision needs remain challenges.

No.	Authors (Year)	Title	Key Findings
26	Daher & Anabousy (2025)	<i>Didactical Knowledge of Generative AI Tools: Writing Math Lessons</i>	Four generative AIs can produce workable lesson plans but vary in pedagogical quality, conceptual depth, and terminology; teacher verification is required.
27	Walkington (2025)	<i>Implications of Generative AI for Mathematics Education</i>	Generative AI accelerates problem solving and personalization but requires ethical oversight, bias monitoring, and human guidance to ensure reflective learning.
28	Jailani et al. (2025)	<i>Blended Learning and Emerging Technologies in Mathematics Education</i>	Emerging technologies offer flexible and engaging learning, but success requires implementation strategies, teacher training, and diverse-context research.
29	Li & Zhang (2022)	<i>Physical Activity and Academic Achievement in Multimodal AI Environments</i>	AI, multimodal learning, and physical activity collectively enhance numeracy, motivation, and health, supporting effective hybrid learning models.
30	Vitale et al. (2025)	<i>Students' Acceptance of the Multimodality of the Social Robot Pepper for Learning Mathematics</i>	The Pepper social robot enhances comfort, emotional engagement, accessibility, and conceptual understanding through combined gestures, visuals, and verbal interaction.

3. Result and Discussion

After completing the selection and analysis process of the thirty articles included in this SLR, the findings were organized thematically to address the formulated research questions. Unlike previous review studies that predominantly focus on multimodal learning or specific technologies in isolation (e.g., Jailani et al., 2025), this SLR integrates evidence on artificial intelligence and multimodal approaches simultaneously, with a specific emphasis on junior high school mathematics learning outcomes related to engagement and conceptual understanding. The synthesis presented in this section therefore does not replicate prior reviews but extends them by mapping the characteristics, mechanisms, and synergistic roles of AI-supported multimodal learning across recent empirical studies. The results are presented according to the sequence of the research questions, from RQ1 to RQ4.

RQ1. Characteristics of AI Implementation in Mathematics Learning

The analysis of thirty articles indicates that the implementation of artificial intelligence (AI) in mathematics learning has evolved toward increasingly adaptive, personalized, and pedagogically integrated systems. Across the reviewed studies, three dominant forms of AI are identified: intelligent tutoring systems (ITS), generative AI tools (e.g., ChatGPT, Gemini, Claude, Perplexity), and multimodal adaptive learning systems. ITS remains the most extensively studied form, as evidenced by Chinjunthuk et al. (2025), Almoubayyed et al. (2023), Rebolledo-Mendez et al. (2022), Nye et al. (2018), and Vest et al. (2022). These studies consistently demonstrate that ITS

supports adaptive scaffolding, worked examples, step-by-step guidance, and self-explanation prompts that strengthen students' mathematical reasoning and conceptual development.

Generative AI represents a more recent research direction, with studies exploring its use for problem generation, dialogic feedback, and mathematical explanation (Arslan & Selek, 2025; Magat & Sangalang, 2024; Liang et al., 2023). However, unlike ITS-focused studies, this line of research emphasizes the necessity of teacher mediation due to the potential for analytical inaccuracies, biased outputs, and inconsistent reasoning in generative systems (Walkington, 2025; Daher & Anabousy, 2025). Consequently, several studies highlight a shift toward hybrid human–AI feedback models, where AI provides rapid responses and teachers guide reflection and conceptual validation. Cosentino et al. (2025) demonstrate that such hybrid configurations yield superior learning outcomes compared to the isolated use of either AI or teacher feedback.

While earlier reviews such as Jailani et al. (2025) primarily emphasize multimodal and immersive technologies, the present SLR extends this perspective by showing that AI implementation characteristics are increasingly defined by their integration within broader learning ecosystems. Emerging technologies such as virtual reality, social robots, and multimodal environments are not treated as standalone tools but as AI-supported systems that combine adaptivity, personalization, automated assessment, and multimodal orchestration. Thus, AI implementation in junior high school mathematics learning is best characterized as a collaborative human–machine process rather than a purely technological intervention.

RQ2. AI's Contribution to Students' Conceptual Understanding in Mathematics

Across the reviewed studies, artificial intelligence demonstrates a consistent and significant contribution to enhancing students' conceptual understanding in mathematics. Unlike prior review studies that predominantly report general learning gains or performance outcomes, this SLR specifically synthesizes how AI supports the process of conceptual construction and sense-making among junior high school students. The findings indicate that AI contributes to conceptual understanding through structured reasoning support, representational coherence, and regulated learning processes.

Studies employing intelligent tutoring systems (ITS) report the strongest and most stable effects on conceptual development. Research by Chinjunthuk et al. (2025), Vest et al. (2022), and Nye et al. (2018) shows that features such as self-explanation prompts, adaptive hints, and step-by-step feedback encourage students to articulate reasoning, understand the logic behind solution procedures, and transfer concepts across problem contexts. These mechanisms help reduce superficial procedural learning and foster deeper conceptual comprehension, particularly in algebra and foundational mathematics topics.

Additional evidence indicates that AI also supports conceptual understanding by improving students' comprehension of mathematical texts and representations. Almoubayyed et al. (2023) report reductions in misconceptions and improved comprehension among students with low reading proficiency, suggesting that AI-mediated scaffolding can bridge linguistic and conceptual gaps. Furthermore, studies by Rzyankina et al. (2024) and Bush (2021) demonstrate that AI-supported interactive visualizations and digital manipulatives enable students to build more

coherent conceptual models by strengthening connections among symbolic, graphical, and numerical representations.

AI-enhanced multimodal learning environments are particularly effective for topics requiring transitions from concrete to abstract reasoning. Vitale et al. (2025) show that AI-supported multimodal tools facilitate early algebra learning by allowing students to manipulate representations dynamically while receiving adaptive feedback. Beyond cognitive mechanisms, affective regulation also plays a crucial role. Rebolledo-Mendez et al. (2022) highlight that AI systems capable of detecting frustration and anxiety can provide timely emotional support, thereby sustaining persistence and promoting deeper conceptual engagement.

Overall, this SLR identifies three core mechanisms through which AI enhances students' conceptual understanding in mathematics: adaptive cognitive scaffolding, multimodal representational support, and regulation of cognitive–affective learning processes. Together, these mechanisms promote meaningful sense-making rather than rote procedural execution, distinguishing the contribution of AI from traditional instructional supports and extending insights beyond those reported in earlier review studies.

RQ3. The Role of Multimodal Learning in Enhancing Student Engagement

Multimodal learning consistently emerges as a key contributor to student engagement in mathematics learning. Studies by Li and Zhang (2022), Bush (2021), and Bernacki and Walkington (2018) demonstrate that multimodal representations strengthen motivation, participation, and cognitive involvement by connecting abstract mathematical ideas with visual, auditory, and kinesthetic experiences. Although Jailani et al. (2025) provide a comprehensive review of multimodal environments, the present SLR complements this work by focusing specifically on how multimodal learning functions within AI-supported instructional systems and how it contributes to engagement across affective, behavioral, and cognitive dimensions.

4. Conclusion

The systematic review of the thirty articles analyzed in this study indicates that the integration of artificial intelligence (AI) and multimodal learning approaches has evolved into one of the most significant innovations in mathematics education, particularly at the junior secondary level. Overall, the SLR findings confirm that AI no longer functions merely as a technical assistant but has become a pedagogical partner capable of providing adaptive scaffolding, personalized learning trajectories, and real-time feedback that strengthens conceptual understanding. At the same time, multimodal learning enriches instructional experiences through combinations of visual, verbal, kinesthetic, and digital interactions that have been shown to enhance students' cognitive, behavioral, and affective engagement. The synergy between these two approaches creates learning environments that are more responsive, reflective, inclusive, and supportive of deeper mathematical sense-making.

In terms of implications, this SLR emphasizes that the success of AI and multimodal learning integration depends heavily on the teacher's role as a facilitator who can guide, monitor, and validate AI-generated outputs to ensure alignment with learning objectives and student

characteristics. Effective implementation requires improving teachers' digital literacy, providing adequate infrastructure, establishing ethical policies regarding data privacy, and aligning curricula with adaptive learning strategies. Moreover, hybrid approaches where teachers and AI collaborate emerge as the most promising model for ensuring that teaching remains human-centered, accountable, and pedagogically sound. Despite offering a comprehensive overview, this study has several limitations. First, the search was limited to Google Scholar via Publish or Perish, Scopus, and ERIC, which may have excluded relevant articles not captured by specific keywords or filters. Second, most analyzed studies employed quantitative designs that may not fully represent the long term impact of AI and multimodal learning on students' conceptual development and engagement. Third, geographical disparities remain evident, as many studies originate from countries with more advanced digital infrastructures, making generalization to the Indonesian context particularly schools with limited technological resources necessary to interpret with caution.

Given these limitations, future research should develop longitudinal studies to examine the long-term influence of AI and multimodal approaches on the development of students' mathematical conceptual understanding. Research should also expand implementation contexts, especially in under-resourced schools, rural areas, and populations of students with special needs. Additionally, future studies should explore how teachers can build competencies in AI and multimodal pedagogical design to ensure that technology integration truly enhances instructional quality rather than serving as a superficial innovation. Developing structured hybrid intelligence models that involve collaboration among teachers, students, and AI represents one of the most strategic directions for strengthening mathematics education in the era of artificial intelligence.

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