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Learning Analytics and Adaptive Learning Systems for Supporting Problem-Solving Skills: A Systematic Review toward Sustainable Education

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ABSTRACT

Objective: *This study aims to systematically examine publication trends, dominant technologies, implementation strategies, educational impacts, challenges, and future directions in learning analytics and adaptive learning systems to improve students' problem-solving skills in sustainable education contexts.* ***Method:*** *Research employed a Systematic Literature Review (SLR) approach following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Articles were collected from Scopus, Web of Science, ScienceDirect, Springer, IEEE Xplore, and Google Scholar using predefined inclusion and exclusion criteria. From 1,487 initial records, 20 articles published between 2022 and 2026 in Scopus-indexed Q1–Q3 journals were selected for in-depth thematic analysis.* ***Results:*** *The findings reveal a growing research trend toward intelligent and personalized learning systems. Intelligent tutoring systems, adaptive learning platforms, predictive analytics, augmented reality, and gamification emerged as the most frequently used technologies. These technologies were found to improve self-regulated learning, collaboration, higher-order thinking, and students' problem-solving performance across various educational contexts.* ***Novelty:*** *This review offers a comprehensive analytical framework that integrates learning analytics, adaptive learning systems, problem-solving skills, and sustainable education, which have largely been examined separately in prior reviews.*

INTRODUCTION

The rapid development of artificial intelligence, big data, learning management systems, and digital learning platforms has significantly accelerated the adoption of data-driven decision-making in education in recent years. Educational institutions are no longer focused solely on digitalizing learning processes but are increasingly developing systems that are more personalized, efficient, and sustainable. This transformation aligns with the broader agenda of sustainable education, which emphasizes inclusive access to learning, resource efficiency, and the development of long-term learner competencies (Yang et al., 2025; Chigbu & Makapela, 2025). However, the widespread adoption of educational technologies has not automatically improved students' higher-order thinking abilities. Many students still struggle to solve complex problems that require multidimensional reasoning and advanced cognitive processing (Wu & Molnár, 2022; OECD, 2023). This issue has become increasingly urgent because analytical thinking and problem-solving are recognized as two of the most essential competencies required in the future workforce (Dumitru & Halpern, 2023; World Economic Forum, 2025). Educational technologies should therefore move beyond improving access to learning and begin fostering complex

thinking skills relevant to global challenges (Rahimi & Oh, 2024; Zou et al., 2025). Consequently, integrating technologies that directly support problem-solving skills has become a strategic priority in sustainable education. Ideally, this widespread integration is expected to go beyond basic access to learning and actively foster complex thinking skills, analytical capabilities, and multidimensional reasoning that are highly relevant to global challenges. Within the framework of sustainable education, these advanced systems should serve as strategic tools that directly cultivate long-term cognitive competencies, ensuring that students are fully prepared with future-ready skills (Wang & Zhu, 2025; Ruan, 2025).

However, the reality in the field shows that the widespread adoption of educational technologies has not automatically improved students' higher-order thinking abilities. One of the fastest-growing approaches to addressing this challenge is learning analytics. This approach enables educational institutions to collect, analyze, and interpret learning data to understand student learning behaviors better and support more accurate instructional decision-making (Feng & Fan, 2024; Kew & Tasir, 2022). Its implementation has expanded rapidly because it helps educators identify engagement patterns, academic difficulties, and potential declines in student performance more efficiently. Despite its growing adoption, empirical evidence regarding its effectiveness remains inconsistent. A previous review identified 6,220 articles, yet only 46 studies met rigorous empirical criteria (Ifenthaler & Yau, 2020). Another systematic review examined 753 publications and found only 56 eligible studies, while only 46% of those studies reported positive impacts on learning outcomes (Heikkinen et al., 2023). More recent evidence also shows that, among 312 analyzed studies, most learning analytics research still focuses on predictive analytics and academic performance rather than on the development of higher-order thinking (Zohar & Ben-Ari, 2022; Alneyadi & Wardat, 2023). Furthermore, many learning analytics dashboards remain centered on performance monitoring rather than explicitly enhancing students' problem-solving skills (Chen et al., 2023; Paulsen & Lindsay, 2024).

Alongside learning analytics, adaptive learning systems have emerged as a more responsive, personalized approach to learning that addresses students' individual needs. These systems can adjust learning materials, pathways, difficulty levels, and feedback in real time based on learner characteristics (Lin et al., 2023; Song et al., 2024). This approach is considered effective because students receive more targeted and efficient learning experiences. However, its pedagogical contribution to the development of problem-solving remains unclear. A recent review published in Computers & Education identified 57 studies on adaptive learning systems, yet most focused primarily on personalization based on learning styles and knowledge levels (Shard et al., 2024; Halkiopoulos & Gkintoni, 2024). Similar findings were reported in 89 studies on AI-personalized learning systems, but most evaluated academic performance rather than problem-solving competencies (Mustapha, 2025; Halkiopoulos & Gkintoni, 2024). Additional challenges remain related to algorithm transparency and recommendation accuracy in adaptive

systems (Khosravi et al., 2022). Moreover, the implementation of artificial intelligence in education continues to emphasize academic automation rather than the development of higher-order thinking (Patrick et al., 2025; Lubbe et al., 2025). In this context, sustainable education is not solely about technological efficiency but also about developing long-term competencies that remain relevant to future societal needs.

Although studies on learning analytics and adaptive learning systems continue to expand, comprehensive syntheses that specifically connect both approaches to problem-solving skills in sustainable education remain limited (Ouyang et al., 2023). A review of learning analytics dashboards identified 38 studies and found relatively small effects on academic achievement (Mahmud & Kurt, 2026; Kaliisa et al., 2023). Another review reported that among 71 studies on intelligent tutoring systems, only a small proportion explicitly measured problem-solving outcomes (Lai & Lin, 2025). Most previous studies have examined engagement, retention, academic achievement, or self-regulated learning separately rather than investigating the development of problem-solving comprehensively (Heikkinen et al., 2023; Paulsen & Lindsay, 2024; Li & Lajoie, 2022). To date, no systematic literature review has comprehensively examined learning analytics, adaptive learning systems, problem-solving skills, and sustainable education within a single integrated analytical framework. This gap is significant because educational institutions need clearer evidence regarding how data-driven adaptive technologies can sustainably improve students' problem-solving skills.

To bridge this critical gap, the proposed innovation in this study is to establish a novel, comprehensive synthesis that, for the first time, integrates learning analytics, adaptive learning systems, problem-solving skills, and sustainable education into a unified analytical framework. Therefore, this study employs a Systematic Literature Review (SLR) approach following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a rigorous, transparent, and replicable article selection process. This review aims to systematically identify publication trends, technological implementations, educational impacts, and future research directions related to learning analytics and adaptive learning systems for improving problem-solving skills in sustainable education (Koutsantonis et al., 2022). The explicit urgency of this research stems from the pressing need to shift educational technology from simple performance tracking to long-term cognitive sustainability. Without a systematic framework to guide this transition, educational institutions will continue to invest in data-driven systems that fail to address the critical decline in higher-order thinking skills, leaving students underprepared for the future workforce. Accordingly, this study addresses the following research questions:

1. What are the publication trends related to learning analytics and adaptive learning systems for supporting problem-solving skills over the past five years?
2. What technologies and implementation strategies are most frequently used to improve students' problem-solving skills?

3. How do learning analytics and adaptive learning systems influence students' problem-solving performance across different educational contexts?
4. What challenges and future directions are identified for integrating these technologies into sustainable education?

RESEARCH METHOD

Research Design

This study employed a Systematic Literature Review (SLR) to identify, evaluate, and synthesize prior studies on the implementation of learning analytics and adaptive learning systems to support problem-solving skills in sustainable education contexts. This method was selected because it provides a comprehensive understanding of research trends, technological developments, and research gaps in rapidly evolving data-driven educational environments. The review process followed the PRISMA guidelines to ensure that the article selection process was conducted systematically, transparently, and reproducibly.

Data Sources and Search Strategy

The article search process was conducted between January and March 2026 using several reputable academic databases, including Scopus, Web of Science, ScienceDirect, and SpringerLink. These databases were selected to ensure broad coverage of the literature while maintaining the quality of the retrieved studies. The search process used Boolean operators with the following search string: ("learning analytics" OR "educational data mining") AND ("adaptive learning system" OR "intelligent tutoring system") AND ("problem-solving skills" OR "higher-order thinking") AND ("sustainable education"). The inclusion criteria covered journal articles published between 2022 and 2026, written in English, peer-reviewed, and available in full-text format.

Editorial papers, non-indexed conference proceedings, book chapters, duplicate records, and studies unrelated to educational contexts were excluded. Duplicate articles were identified and removed using Mendeley prior to the screening process. The research stages included problem identification, formulation of research questions, database searching, article screening, data extraction, thematic analysis, and synthesis of findings. The data collection workflow is shown in Figure 1 below.

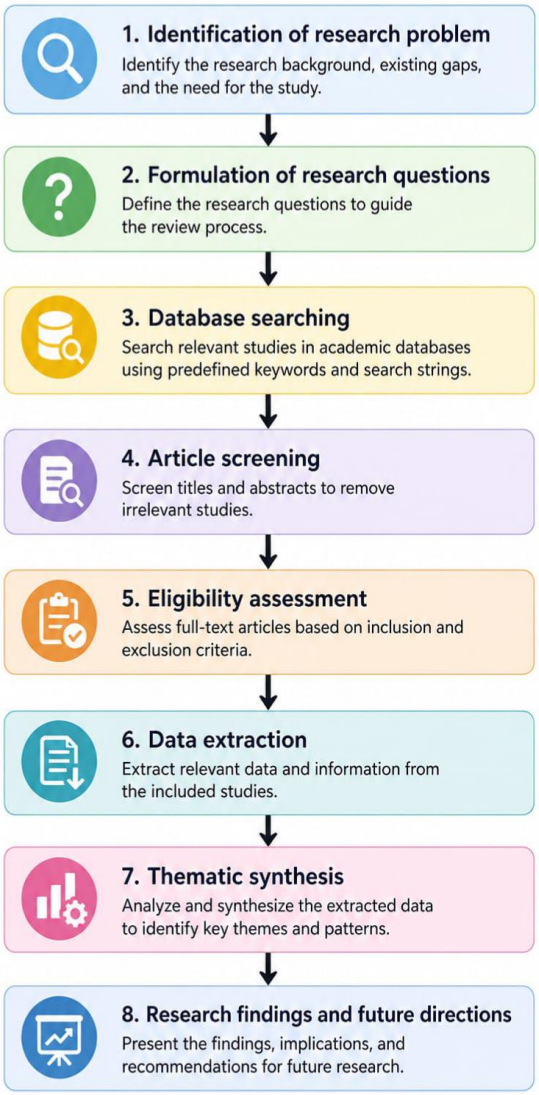

Figure 1. Research Framework of Systematic Literature Review.

Article Selection Process

The article selection process followed the PRISMA stages consisting of identification, screening, eligibility, and inclusion (Islam et al., 2025). During the initial identification stage, 1,487 articles were retrieved from all selected databases. After removing 312 duplicate records, a total of 1,175 articles remained for title and abstract screening. During the screening stage, 842 articles were excluded because they were not aligned with the research focus, such as studies that only discussed technical system development, did not examine problem-solving skills, or focused solely on general academic achievement. Subsequently, 333 full-text articles were assessed for eligibility. At the eligibility stage, 241 articles were excluded because they did not meet methodological criteria, lacked sufficient empirical evidence, or did not address sustainable education issues. This process resulted in 92 articles that were used for general research mapping, publication trends analysis, and topic distribution analysis.

A secondary selection process was then conducted to identify studies for in-depth review. This stage prioritized studies with the highest relevance to the research questions, complete empirical findings, and journals indexed in Scopus quartiles Q1, Q2, and Q3. This criterion ensured that the in-depth synthesis relied on stronger and more credible academic evidence. As a result, 20 core studies were selected for detailed analysis. The data analysis from the Scopus database is shown in Figure 2 below.

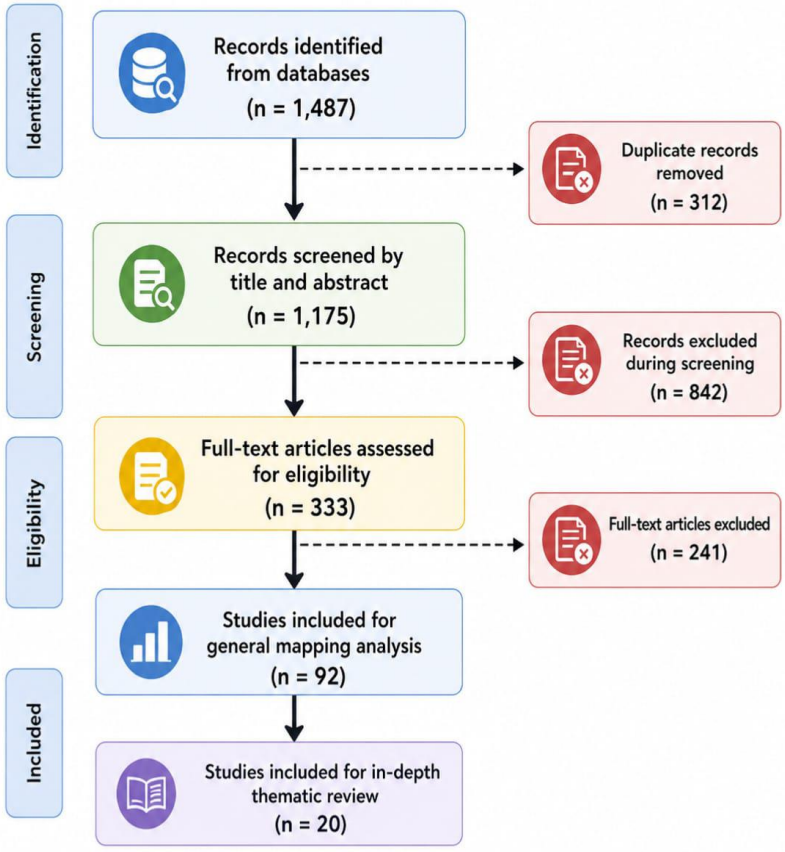

Figure 2. PRISMA Flow Diagram.

Data Analysis

The 92 selected articles were used to analyze publication trends, country distribution, educational levels, and dominant technological developments in learning analytics and adaptive learning systems research. Meanwhile, the 20 core studies were analyzed in greater depth using descriptive qualitative synthesis and thematic analysis. The in-depth analysis was conducted using a research synthesis table that included information on authors, publication year, journal quartile, country of study, educational level, technology used, research methods, sample characteristics, and key findings on problem-solving skills. The findings were then categorized into major themes, including research trends, implementation strategies, impacts on problem-solving skills, and implementation challenges in sustainable education contexts. The final synthesis was used to identify dominant research patterns, research gaps, and future research directions.

RESULTS AND DISCUSSION

Results

The integration of learning analytics and adaptive learning systems has become an important strategy for improving students' problem-solving skills in digital learning environments. As educational systems increasingly adopt artificial intelligence, educational data mining, and personalized learning technologies, students are expected to solve more complex problems that require analytical reasoning, decision-making, and higher-order thinking skills. However, conventional instructional approaches often fail to provide personalized feedback and adaptive support needed to develop these competencies effectively. In response to this challenge, recent studies have increasingly explored learning analytics, intelligent tutoring systems, adaptive learning platforms, and AI-driven feedback mechanisms to support students' problem-solving processes. Based on the distribution of selected studies published between 2022 and 2026, research trends indicate a shift from predictive analytics and student performance monitoring in earlier studies toward more advanced adaptive systems, real-time feedback models, intelligent tutoring systems, and personalized learning environments in recent studies. This trend demonstrates that educational technologies are evolving from passive monitoring tools into intelligent systems that actively support the development of problem-solving skills and sustainable learning outcomes.

Recent findings also indicate that these technologies can improve students' cognitive engagement, self-regulated learning, critical thinking, and independent problem-solving performance across various educational contexts. Through personalized recommendations, adaptive assessments, and real-time learning interventions, students can receive more targeted support based on their individual learning needs. This study included 20 articles because they met all predefined inclusion criteria: publication between 2022 and 2026, in Scopus-indexed Q1–Q3 journals, and explicit discussion of learning analytics, adaptive learning systems, intelligent tutoring systems, or problem-solving development. After applying PRISMA-based screening procedures, these 20 studies were deemed sufficiently representative for an in-depth thematic synthesis. Table 1 presents the characteristics of the selected studies, including author, publication year, article title, journal quartile, research method, and key findings.

Table 1. Characteristics of the selected studies.

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
1	Lauren Genith Isaza Domínguez, Fabian Velasquez Clavijo, Antonio	2024	A Sustainable Educational Tool for Engineering Education Based on Learning Styles, AI,	Sustainability (Q1)	Quantitative experimental system development involving 72 engineering students during a 16-	The AI model successfully predicted learning style transitions and generated personalized recommendatio

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
	Robles-Gómez, & Rafael Pastor-Vargas		and Neural Networks Aligning with the UN 2030 Agenda for Sustainable Development		week semester. The study integrated Long Short-Term Memory (LSTM) neural networks, Felder-Silverman learning style classification, chatbot-based assistance, and adaptive recommendation algorithms. Student behavioral data were continuously analyzed to personalize learning pathways.	ns. Students demonstrated improved learning engagement and adaptive learning efficiency. The study is highly relevant because it explicitly connects AI personalization with sustainable education goals, although direct problem-solving measurement remained limited.
2	Christos Halkiopoulos & Evgenia Gkintoni	2024	Leveraging AI in E-Learning: Personalized Learning and Adaptive Assessment through Cognitive Neuropsychology—A Systematic Analysis	Electronics (Q2)	Systematic review analyzing AI-based adaptive assessment systems, neurocognitive personalization models, learner profiling systems, and intelligent feedback mechanisms across multiple educational contexts.	The review found that adaptive AI systems improved assessment precision, individualized learning experiences, and responsiveness to learner cognitive needs. The article supports your topic because adaptive assessment helps identify problem-solving weaknesses early.
3	Uchechukwu C. Apoki,	2022	The Role of Pedagogical Agents in	Sustainability (Q1)	Systematic literature review	The study found that pedagogical agents improved

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
	Ahmed M. A. Hussein, Hazar K. M. Al-Chalabi, Costin Badica, & Monica L. Mocanu		Personalised Adaptive Learning: A Review		examining AI pedagogical agents, conversational agents, adaptive tutoring assistants, and personalized instructional support models.	learner motivation, feedback immediacy, engagement, and adaptive communication. These agents help scaffold learners during complex tasks, which indirectly supports problem-solving development.
4	Liu Ren, Kyung Lee, & Lily May	2025	A Systematic Review Exploring AI's Role in Self-Regulated Learning within Education Contexts	IEEE Access (Q1)	Systematic review of AI-supported self-regulated learning systems involving monitoring dashboards, recommendation engines, predictive analytics, and adaptive feedback systems.	The review found that AI improved goal-setting, learner autonomy, reflection, and monitoring behaviors. These factors are strongly associated with independent problem-solving performance.
5	Changhyun Song, Seung Yeon Shin, & Kyu Sik Shin	2024	Implementing the Dynamic Feedback-Driven Learning Optimization Framework: A Machine Learning Approach to Personalize Educational Pathways	Applied Sciences (Q2)	Machine learning development study using real-time student behavioral data, dynamic feedback loops, predictive recommendation systems, and adaptive intervention algorithms.	The system improved recommendation accuracy and optimized personalized learning paths. The study is relevant because adaptive feedback helps students solve learning difficulties more efficiently.
6	Claudio Giovanni Demartini,	2024	Artificial Intelligence Bringing	Sustainability (Q1)	Case study evaluating implementatio	Results showed improved learner

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
	Luca Sciascia, Alberto Bosso, & Francesco Manuri		Improvements to Adaptive Learning in Education: A Case Study		n of AI-driven adaptive learning systems in digital education settings. The study examined personalized recommendation models and adaptive content sequencing.	engagement, personalization quality, and instructional flexibility. The study supports sustainable education by promoting efficient individualized learning systems.
7	Jing Huang, Yifan Zhong, & Xia Chen	2025	Adaptive and Personalized Learning in STEM Education Using High-Performance Computing and Artificial Intelligence	The Journal of Supercomputing (Q2)	Experimental study integrating high-performance computing, AI recommendation engines, adaptive content sequencing, and personalized STEM learning environments.	Students demonstrated improved learning efficiency and faster mastery of complex STEM content. This supports problem-solving development in technical disciplines.
8	Liang Lim, Siew H. Lim, & Wai Y. R. Lim	2023	Efficacy of an Adaptive Learning System on Course Scores	Systems (Q2)	Experimental comparative study between adaptive learning users and traditional instruction groups using academic performance measurement.	Students in adaptive learning environments achieved significantly higher course scores. However, problem-solving indicators were measured indirectly through performance outcomes.
9	Moses Kyambade, Agnes	2025	Exploring the Evolution of Artificial	Cogent Education (Q2)	Review study examining the evolution of	The study identified a major shift

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
	Namatovu, & Male Ssentumbwe		Intelligence in Education: From AI-Guided Learning to Learner-Personalized Paradigms		AI-driven education systems from automation models toward personalization ecosystems.	toward learner-centered AI systems that emphasize adaptability, personalization, and long-term competency development, aligning with sustainable education frameworks.
10	Fatma Gizem Karaoglan Yilmaz	2022	Utilizing Learning Analytics to Support Students' Academic Self-Efficacy and Problem-Solving Skills	The Asia-Pacific Education Researcher (Q2)	Quasi-experimental research involving university students in online learning environments. The study used learning analytics dashboards, behavioral tracking data, student interaction logs, self-efficacy scales, and problem-solving assessment instruments to evaluate learning performance.	The study found significant improvements in students' academic self-efficacy and problem-solving skills after receiving analytics-based feedback. Students became more aware of their learning behaviors and improved their decision-making strategies. This study is one of the strongest direct evidences linking learning analytics with problem-solving improvement.
11	Aijun He, Wenjie Yuan, Lee Lee S., & Tian Tian	2025	AI-Driven Predictive Models for Optimizing Mathematics Education Technology: Enhancing Decision-Making Through	Smart Learning Environments (Q1)	Meta-analysis and predictive modeling study examining educational data mining techniques, machine learning prediction	The study found that predictive analytics significantly improved early identification of struggling learners and enabled faster instructional intervention.

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
			Educational Data Mining and Meta-Analysis		models, and mathematics learning performance datasets. The study analyzed algorithm accuracy and instructional optimization strategies.	This helps problem-solving development because students receive timely support before cognitive failure occurs.
12	Ying Zheng & Di Li	2025	Learning Analytics-Informed Teaching Strategies: Enhancing Interactive Learning in STEM Education	Interactive Learning Environments (Q1)	Mixed-method study involving classroom analytics, student interaction tracking, instructor interventions, and qualitative interviews in STEM education settings.	Learning analytics improved teacher decision-making, student participation, and instructional responsiveness. The study showed that analytics-based interventions created more interactive learning environments that supported analytical reasoning.
13	Hasan Ateş	2025	Integrating Augmented Reality into Intelligent Tutoring Systems to Enhance Science Education Outcomes	Education and Information Technologies (Q1)	Experimental study involving science students using an augmented reality-integrated intelligent tutoring system. The study utilized pretest-posttest assessments, student interaction monitoring, and conceptual	The integration of augmented reality significantly improved conceptual understanding, learner engagement, and scientific problem-solving performance. Students demonstrated better visualization of abstract scientific

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
					understanding evaluations to examine learning outcomes.	concepts, which helped them solve complex tasks more effectively.
14	Kai Kong, Hanan F. Isleem, Rami Aluvalu, Ghulam G. Tejani, & Ahmed S. M. Metwally	2025	Real-Time Cognitive and Emotional State Tracking in Intelligent Tutoring Systems for Enhanced Learning Outcomes	Journal of Big Data (Q1)	Artificial intelligence model development study using real-time emotional recognition systems, cognitive monitoring algorithms, behavioral analytics, and adaptive tutoring interventions.	The system detected learner frustration, confusion, and disengagement in real time, enabling immediate instructional adjustments. This improved learner persistence during difficult problem-solving activities.
15	Jirawat Kumnuan sin, Jaitip Khlaisang, & Panita Koraneeki j	2022	Design of Cloud-Based Adaptive Learning System to Promote Creative Problem Solving for the 21st Century Learners	TEM Journal (Q3)	Research and development study using cloud-based adaptive learning architecture, expert validation, and student implementatio n testing. The system was specifically designed to enhance creative problem-solving.	The platform improved students' creative problem-solving skills through adaptive content delivery, flexible learning access, and real-time learning adjustments. This study directly aligns with your problem-solving variable.
16	Khaled Soltani & Nacira Hocine	2025	An Adaptive Learning System to Enhance Collaborative Problem-Solving	International Journal of e-Collaboration (Q3)	Experimental study examining adaptive collaborative learning systems, peer interaction	The study found significant improvements in collaborative problem-solving performance, teamwork coordination,

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
					analytics, collaborative task performance, and group problem-solving assessments.	and adaptive task completion efficiency.
17	Xiaohui Yang & Yan Ping Xin	2026	The Use of an Intelligent Tutoring Program to Promote Independent Problem-Solving Skills of Students With Learning Disabilities or Difficulties	Learning Disability Quarterly (Q1)	Experimental intervention involving students with learning disabilities. The study used tutoring software, structured intervention procedures, and independent problem-solving assessments.	Students demonstrated improved independent problem-solving performance and increased learning confidence. This study highlights the inclusive dimension of sustainable education.
18	Xinyi Zhong & Zhiting Zhan	2025	An Intelligent Tutoring System for Programming Education Based on Informative Tutoring Feedback: System Development, Algorithm Design, and Empirical Study	Interactive Technology and Smart Education (Q2)	System development and empirical evaluation study involving programming students. The system used algorithm-based feedback models, learner error detection, and adaptive tutoring interventions.	Students receiving intelligent feedback demonstrated better debugging skills, programming problem-solving performance, and higher task completion success rates.
19	Chia-Hung Lai & Chih-Yuan Lin	2025	Analysis of Learning Behaviors and Outcomes for Students with Different Knowledge	Applied Sciences (Q2)	Case study using behavioral analytics, coding performance assessment, learner	The system improved coding performance for both low-performing and high-performing students

No	Author	Year	Title	Journal & Quartile	Method	Key Findings
			Levels: A Case Study of Intelligent Tutoring System for Coding and Learning (ITS-CAL)		classification models, and adaptive tutoring support.	through personalized instructional pathways.
20	Aruzhan M. Kassenkhan, Ainur N. Moldagulova, & Vladimir V. Serbin	2025	Gamification and Artificial Intelligence in Education: A Review of Innovative Approaches to Fostering Critical Thinking	IEEE Access (Q1)	Systematic review examining gamification models, AI-based adaptive learning systems, motivational design frameworks, learner engagement mechanisms, and critical thinking development across digital education settings.	The review found that integrating gamification with AI significantly improved learner motivation, participation, persistence, and critical thinking performance. Adaptive gamified systems encouraged students to engage in more complex decision-making processes, which indirectly strengthened problem-solving abilities. However, long-term sustainability impacts remain underexplored.

Discussion

Publication Trends of Learning Analytics and Adaptive Learning Systems for Supporting Problem-Solving Skills

The review of 20 selected studies revealed a consistent increase in publications on learning analytics and adaptive learning systems to support problem-solving skills during 2022–2026. The publication distribution comprised three studies in 2022, one in

2023, six in 2024, eight in 2025, and two in 2026, indicating rapidly growing scholarly interest in this field over the past two years. During the early phase, studies primarily focused on basic adaptive personalization through pedagogical agents, learning dashboards, and adaptive content recommendation systems designed to improve learning efficiency. These early systems mainly adjusted instructional content based on learning preferences, prior knowledge, and engagement patterns without explicitly targeting problem-solving competencies. Previous studies demonstrated that early adaptive systems were largely oriented toward improving academic achievement and learning efficiency rather than directly developing higher-order thinking skills (Apoki et al., 2022; Karaoglan Yilmaz, 2022; Lim et al., 2023). In this phase, problem-solving skills were often positioned as indirect outcomes of personalized learning interventions. This trend suggests that early research emphasized adaptive delivery systems rather than explicit problem-solving development (Gutierrez et al., 2025).

A substantial shift emerged in 2024 as studies began to integrate artificial intelligence, machine learning, and adaptive feedback mechanisms into educational systems. Neural network-based learning systems were increasingly linked to sustainable education goals and long-term competency development (Isaza Domínguez et al., 2024). Real-time adaptive feedback systems were introduced to personalize learning pathways based on student performance (Song et al., 2024). Artificial intelligence also improved recommendation accuracy in adaptive learning environments (Demartini et al., 2024). Additionally, adaptive assessment systems became more widely implemented to match task difficulty with learner capabilities (Halkiopoulos & Gkintoni, 2024). These findings indicate that problem-solving began to emerge as a more explicit instructional objective during this period.

From 2025 to 2026, research evolved toward more advanced intelligent learning ecosystems that were increasingly real-time, contextual, and interactive. Recent studies integrated augmented reality, emotional analytics, intelligent tutoring systems, predictive learning algorithms, collaborative adaptive learning environments, and gamification strategies into educational settings. Augmented reality improved conceptual visualization in science learning (Ateş, 2025). Emotional analytics systems were developed to detect learners' cognitive and emotional states during problem-solving activities (Kong et al., 2025). Collaborative adaptive systems improved collaborative problem-solving performance (Soltani & Hocine, 2025). Intelligent tutoring systems were also expanded to support students with learning disabilities (Yang & Xin, 2026). These findings suggest that research has shifted from static personalization toward intelligent ecosystems designed to support sustainable higher-order problem-solving competencies.

Dominant Technologies and Implementation Strategies

The review identified five dominant technologies frequently used to enhance students' problem-solving skills. Among the 20 reviewed studies, six focused on intelligent

tutoring systems, five on adaptive learning systems, four on learning analytics, three on predictive artificial intelligence systems, and two on immersive technologies such as augmented reality and gamification. This distribution indicates that intelligent tutoring systems have become the most dominant approach because they provide direct problem-solving support through automated feedback mechanisms. These systems allow students to receive immediate assistance when encountering difficulties during complex tasks. This trend demonstrates a shift from passive monitoring systems toward direct intervention technologies (Hong et al., 2025).

The first major implementation strategy involved using learning analytics to identify learning behaviors and predict academic difficulties. These systems were used to detect learning obstacles, predict academic performance, and support timely interventions based on real-time learner data. Learning analytics dashboards improved students' academic self-efficacy and problem-solving abilities by enabling learners to monitor their progress (Karaoglan Yilmaz, 2022). Data-driven instructional decisions also enabled educators to redesign learning activities based on learner interactions (Zheng & Li, 2025). Predictive analytics further improved decision-making in mathematics education contexts (He et al., 2025). These findings suggest that learning analytics serves as an early diagnostic mechanism in the development of problem-solving.

The second strategy involved adaptive personalization through dynamic adjustment of learning materials, task difficulty, and instructional pathways. Adaptive assessment systems enabled learners to receive challenges aligned with their competency levels (Halkiopoulos & Gkintoni, 2024). Adaptive STEM learning environments improved complex problem-solving performance (Huang et al., 2025). Personalized adaptive systems also improved academic achievement and learning efficiency (Lim et al., 2023). Artificial intelligence recommendation systems further enhanced individualized learning experiences (Demartini et al., 2024). These findings highlight the importance of personalized instruction in supporting the development of problem-solving skills.

The final emerging strategy involved immersive learning technologies such as augmented reality and gamification. Augmented reality supported learners' understanding of abstract scientific concepts through visualization (Ateş, 2025). AI-based gamification improved learner persistence during complex problem-solving activities (Kassenkhan et al., 2025). These technologies improved both engagement and conceptual understanding. This suggests that problem-solving development requires not only personalization but also interactive learning experiences.

Effects Across Different Educational Contexts

The review found that the effects of learning analytics and adaptive learning systems varied across educational contexts. In higher education settings, learning analytics was primarily used to improve self-regulated learning, academic self-efficacy, and independent problem-solving skills. Learning analytics dashboards improved students' ability to monitor their learning progress and make academic decisions independently

(Karaoglan Yilmaz, 2022). Artificial intelligence systems also supported self-regulated learning behaviors among university students (Ren et al., 2025). These findings suggest that technology enhances problem-solving by strengthening learner autonomy.

In STEM and engineering education, adaptive systems demonstrated strong impacts on complex problem-solving performance. Artificial intelligence-based systems improved personalized competency development in engineering education (Isaza Domínguez et al., 2024). Adaptive STEM platforms improved students' ability to solve complex scientific problems (Huang et al., 2025). Augmented reality also improved scientific reasoning through better visualization of abstract concepts (Ateş, 2025). These findings indicate that adaptive technologies are particularly effective in disciplines that require high levels of conceptual reasoning.

In programming education, intelligent tutoring systems demonstrated particularly strong impacts because they provided immediate feedback during debugging and coding activities. Adaptive tutoring systems improved debugging accuracy and problem-solving efficiency (Zhong & Zhan, 2025). Students with varying levels of prior knowledge exhibited distinct problem-solving patterns in intelligent tutoring environments (Lai & Lin, 2025). Step-by-step tutoring assistance accelerated technical problem-solving processes. These findings highlight the effectiveness of intelligent tutoring systems in procedural learning contexts.

In special education contexts, adaptive technologies contributed significantly to inclusive learning environments. Intelligent tutoring systems improved independent problem-solving skills among students with learning disabilities (Yang & Xin, 2026). These systems enabled learners to progress at their own pace. This flexibility supports broader sustainable education goals related to educational equity and inclusion.

Challenges and Future Directions Toward Sustainable Education

Despite promising findings, several challenges remain in implementing learning analytics and adaptive learning systems. The first challenge involves low algorithm transparency. Many artificial intelligence systems still function as black boxes, making it difficult for educators to understand how recommendations are generated. Explainable artificial intelligence has been identified as a critical requirement for future educational systems (Khosravi et al., 2022). Limited transparency may reduce trust in adaptive technologies and hinder large-scale adoption.

The second challenge involves data privacy and ethical concerns. Learning analytics requires large-scale student behavioral data to generate personalized recommendations. Students' acceptance of learning analytics systems is strongly influenced by transparency regarding data usage (Tsai et al., 2023). Several studies also highlighted infrastructure limitations in developing countries. High implementation costs remain a major challenge for educational institutions. These issues may widen digital inequality if not properly addressed.

The third challenge involves limited longitudinal evidence. Most existing studies focus on short-term outcomes such as engagement, satisfaction, and academic achievement. The long-term impact of these technologies on problem-solving competencies remains underexplored (Kaliisa et al., 2023; Paulsen & Lindsay, 2024). Sustainable education requires long-term competency development rather than short-term performance gains (Leal Filho et al., 2023). Future studies should develop longitudinal assessment models, scalable adaptive learning ecosystems, ethical learning analytics frameworks, and explainable artificial intelligence systems to ensure sustainable educational transformation.

CONCLUSION

Fundamental Finding: This systematic literature review confirms that learning analytics and adaptive learning systems have strong potential to enhance students' problem-solving skills in sustainable education. Based on 20 studies published between 2022 and 2026, the findings show a shift from basic learning monitoring toward intelligent, personalized systems that integrate artificial intelligence, adaptive feedback, intelligent tutoring systems, predictive analytics, augmented reality, and gamification. These technologies increasingly support higher-order thinking, self-regulated learning, and collaborative problem-solving skills. **Implication:** The findings suggest that educational institutions should move beyond merely adopting digital tools and focus on designing data-driven learning environments that support long-term competency development. This review provides practical insights for educators, curriculum developers, and policymakers in aligning educational technology with sustainable learning goals. **Limitation:** This review only included studies published between 2022 and 2026 from Scopus-indexed Q1–Q3 journals. Differences in educational contexts, technological models, and assessment indicators may limit direct comparison across studies. **Future Research:** Future studies should examine long-term impacts, ethical challenges, and implementation barriers across broader educational settings. Further research is needed to ensure that intelligent learning technologies remain effective, inclusive, and sustainable in preparing learners to solve complex future challenges.

AUTHOR CONTRIBUTIONS

Qurrota A'yun contributed to the conceptual framework, research design, and validation process; **Rahmatta Thoriq Lintangesukmanjaya & Dwikoranto** was involved in methodology development, data analysis, sourcing references, and drafting the manuscript; **Neisya Azaria Adinda Putri** handled data management; **Noval Maleakhi Hulu** was involved in methodology development. All listed authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

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