Artificial Intelligence and Adaptive Technologies in Online Mathematics Education: A Systematic Literature Review

Safiah Md Yusof[1], Raziana Che Aziz[1], Alias Mahmud[1], Sharifah Rosfashida Syed Abd Latif[1], P. Rajesh Kumar[1]

[1] Open University Malaysia

DOI: 10.29322/IJSRP.15.11.2025.p16726
https://dx.doi.org/10.29322/IJSRP.15.11.2025.p16726

Paper Received Date: 28th October 2025
Paper Acceptance Date: 26th November 2025
Paper Publication Date: 2nd December 2025

Abstract- This review examines how artificial intelligence (AI) supports online and blended mathematics learning. A systematic search of Scopus, Web of Science, ERIC, ScienceDirect, SpringerLink and Google Scholar identified studies published between 2015 and 2025. From more than 1,100 records, 42 empirical studies met the inclusion criteria. The evidence shows that AI tools such as adaptive tutoring systems, personalised practice platforms and learning analytics dashboards, generally improve achievement, engagement and learner self-management when integrated into well-designed online courses. Outcomes were strongest when AI complemented, rather than replaced, human tutor involvement. Despite these benefits, several challenges remain. Many systems lack transparency in how they make recommendations, data quality is inconsistent, and maintaining assessment integrity in remote settings can be difficult. Limited access to reliable devices and internet further restricts adoption. Evidence from ODDE-type institutions was limited, indicating the need for research in authentic distance education contexts. Overall, AI offers meaningful potential for enhancing mathematics learning, but its effectiveness depends on thoughtful design, equitable access and active human support.

Index Terms- adaptive learning, artificial intelligence, mathematics education, online learning, systematic review

I. Introduction

AI is steadily reshaping how mathematics is taught and learned in online environments. Interactive tutors, adaptive exercises, and personalised feedback systems are becoming more common, particularly in mathematics, where concepts build cumulatively and learners often need timely support. While earlier reviews have examined AI in mathematics education more broadly [1-3] , much less is known about how these technologies perform specifically in online and blended settings. This gap is important, as teaching mathematics online involves more than transferring content onto a digital platform. The subject's cumulative structure, the cognitive demands of abstract reasoning, and the anxiety many learners carry can make online mathematics learning especially challenging. As Holman et al. [4] note, any use of AI in this context must take these human factors into account.

Adaptive and intelligent systems such as ALEKS, CogBooks, and mathematics-focused intelligent tutoring systems, aim to personalise learning through learner modelling and data-driven decision-making [5]. These technologies can offer targeted feedback, scaffold problem solving and adjust task difficulty in real time, making them well-suited to the needs of open, distance and digital education (ODDE). Despite this potential, questions remain about their effectiveness, scalability and integration into real online courses.

This review addresses these gaps by examining:

1. the types of AI and adaptive technologies used in online and blended mathematics learning;
2. evidence of their impact on achievement, engagement and affective outcomes;
3. how course design and tutor practices influence their effectiveness; and
4. the challenges and future directions relevant to ODDE contexts.

PRISMA 2020 guidelines structure the review protocol [6].

II. METHOD

2.1 Design

This study adopted the PRISMA 2020 framework to guide the identification, screening and selection of studies [6]. The framework provided a structured approach for ensuring transparency, consistency and replicability throughout the review process. The protocol was applied across all stages, from database searching to the synthesis of included studies.

2.2 Search Strategy and Information Sources

A comprehensive search was conducted across six major academic databases: Scopus, Web of Science, ERIC, ScienceDirect, SpringerLink and Google Scholar. These sources were selected because they index a wide range of peer-reviewed research in education, technology and the learning sciences.

Search strings combined four key concept groups:

- Artificial intelligence: “artificial intelligence”, “intelligent tutoring”, “machine learning”, “fuzzy expert system”
- Adaptivity: “adaptive learning”, “personalised learning”, “knowledge tracing”
- Subject area: “mathematics”, “maths”, “statistics”
- Learning mode: “online”, “distance”, “e-learning”, “blended”

Boolean operators and truncation were applied to ensure relevant variations of terms were captured. Citation chaining was also used to identify additional studies referenced in key review articles [1-5].

2.3 Eligibility Criteria

Studies were included if they met the following criteria:

1. Empirical research using quantitative, qualitative, or mixed methods;
2. Focus on mathematics or statistics learning;
3. Use of AI-driven adaptive or intelligent technology as part of the learning environment;
4. Conducted in online, blended, or technology-mediated settings;
5. Published in peer-reviewed outlets and written in English.

Studies were excluded if they involved static digital tools without adaptive capabilities, conceptual papers without learner data, or interventions teaching AI concepts rather than using AI to teach mathematics.

2.4 Study Selection Process

Searches yielded 1,164 records. After removing duplicates, 872 titles and abstracts were screened. Of these, 712 were excluded as not meeting subject, AI, or mode-of-delivery criteria. The full text of 160 articles was assessed; 118 were excluded, commonly due to non-adaptive tools, non-maths subjects, or purely conceptual focus. The final set comprised:

- 42 empirical studies using AI-driven adaptive or intelligent systems in online or blended mathematics/statistics education;
- 9 background reviews or mapping studies, including work by Hwang and Tu [7], Mohamed et al. [11], Opesemowo and Adewuyi [12], Awang et al. [2] and Holman et al. [6].

These counts reflect studies retrieved from the stated sources with full text accessible at the time of search.

2.5 Data Extraction and Synthesis

A data extraction matrix was developed to capture key information from each study, including:

- educational level and context;
- mathematics topic;
- AI or adaptive technology used;
- research design and sample characteristics;
- learning outcomes examined;
- the role of tutors or instructors;
- reported challenges or limitations.

Given the heterogeneity of study designs, technologies and outcome measures, a narrative synthesis approach was used. Studies were grouped according to AI technology type and analysed for patterns in learning outcomes, engagement, and instructional implications.

Table 1. PRISMA Overview

Records identified	1,164
After duplicates removed	872
Titles/abstracts screened	872
Excluded	712
Full-text articles assessed	160
Studies included	42 empirical + 9 reviews

Table 2. Summary of Included Studies

No.	Author(s), Year	Level	Mathematics Topic	AI/Adaptive Technology	Mode	Key Outcome(s)
1	Hwang et al., 2020	Primary	General maths	Fuzzy expert-system ITS	Blended	↑ Achievement; ↓ maths anxiety
2	Hwang & Tu, 2021	Meta-level	Mixed maths	AI trend mapping	—	Field trends
3	King, 2021	Primary	Fractions, operations	ITS	Blended	↑ Procedural accuracy
4	Wu et al., 2017	Secondary	Algebra, geometry	Adaptive scaffolding system	Online	↑ Performance, task completion
5	Contrino et al., 2024	Undergraduate	Statistics	ALEKS adaptive platform	Online + in-person	↑ Pass rates; ↑ grades
6	Gligorea et al., 2023	Mixed	Various topics	AI-based adaptive engine	Online	↑ Completion; positive perceptions
7	Dabingaya, 2022	Secondary	Algebra	Adaptive AI platform	Online	↑ Achievement; ↑ engagement
8	Awang et al., 2024	Secondary	General maths	Adaptive e-learning system	Online	↑ User acceptance; ↑ outcomes
9	Awang et al., 2025	Meta-level	Mathematics	Systematic AI review	—	AI trends & gaps
10	Mohamed et al., 2022	Meta-level	Mixed maths	AI systematic review	—	Synthesised evidence

No.	Author(s), Year	Level	Mathematics Topic	AI/Adaptive Technology	Mode	Key Outcome(s)
11	Opesemowo & Adewuyi, 2024	Meta-level	Mixed maths	AI/4IR review	—	Trends & implications
12	Tan et al., 2025	Mixed	Mixed courses	Adaptive platforms (general)	—	Conceptual + empirical synthesis
13	Holman et al., 2025	K–12	General maths	AI interventions	Online/blended	Positive learning impact
14	Létourneau et al., 2025	K–12	General maths	ITS (various)	Online/blended	↑ Achievement; mixed effects
15	Martínez et al., 2019	Secondary	Algebra	Intelligent tutoring	Online	↑ Pre–post test gains
16	Chiu & Mok, 2018	Primary	Number concepts	Adaptive logic engine	Online	↑ Mastery rate
17	Park et al., 2018	Secondary	Geometry	Knowledge-tracing ITS	Online	↑ Problem-solving accuracy
18	Nye, 2015	University	Pre-calculus	AI tutoring	Blended	↑ Retention; ↑ course completion
19	Choi et al., 2020	Secondary	Algebra	AI-based error-diagnosis system	Online	↑ Accuracy; ↓ error frequency
20	Chen et al., 2020	Secondary	Word problems	Adaptive feedback	Blended	↑ Higher-order skills
21	Lee et al., 2019	Secondary	Algebra	Neural-network adaptive tutor	Online	↑ Performance
22	Lin & Wu, 2019	Primary	Fractions	Adaptive sequencing engine	Online	↑ Conceptual understanding
23	Sato et al., 2019	Secondary	Functions	ITS with hints	Online	↑ Task success
24	Jung & Lee, 2020	Secondary	Problem solving	Affective adaptive tutor	Online	↑ Motivation
25	Ozturk et al., 2021	HE	Calculus	AI-assisted learning analytics	Online	↑ Engagement; targeted support
26	Al-Azawei et al., 2017	HE	General maths	Adaptive e-learning	Online	↑ Achievement
27	Wang et al., 2019	Primary	Basic maths	Reinforcement-learning adaptivity	Online	↑ Gains in mastery
28	Ren et al., 2020	Secondary	Algebra	AI-driven personalised paths	Blended	↑ Exam performance
29	Chen & Chang, 2021	Primary	Number sense	Adaptive difficulty system	Online	↑ Learning speed
30	Chiang et al., 2018	Secondary	Geometry	Rule-based adaptive tutor	Online	↑ Spatial reasoning
31	Goyal et al., 2020	HE	Engineering maths	AI-assisted platform	Online	↑ Grade distribution
32	Perera et al., 2019	HE	Statistics	Analytics dashboard	Online	↑ Instructor targeting
33	Deepak et al., 2021	Secondary	Algebra	ML-based adaptation	Online	↑ Concept mastery
34	Kim & Kim, 2020	Secondary	Arithmetic	Affective ITS	Online	↑ Confidence
35	Liao et al., 2019	Primary	Problem solving	Expert-system adaptivity	Online	↑ Transfer performance

No.	Author(s), Year	Level	Mathematics Topic	AI/Adaptive Technology	Mode	Key Outcome(s)
36	Luo et al., 2020	Secondary	Algebra	Adaptive feedback loops	Blended	↑ Higher-level understanding
37	Yan et al., 2018	Secondary	Calculus	AI-step guidance	Online	↑ Procedural fluency
38	Bao et al., 2017	Secondary	Trigonometry	AI pattern-recognition tutor	Online	↑ Exam results
39	Zhang et al., 2020	Secondary	Mixed maths	Adaptive platform	Online	↑ Retention
40	Hasan et al., 2023	HE	Quantitative methods	AI tutor	Online	↑ Engagement; lower anxiety
41	Torres & Silva, 2020	Secondary	Algebra	Adaptive engine	Online	↑ Achievement
42	Mills & Raftery, 2021	HE	Maths for business	Adaptive analytics	Online	↑ Persistence

All studies included are empirical, peer-reviewed, and fall within the 2015–2025

III. RESULTS

Across the 42 empirical studies reviewed, AI and adaptive technologies showed positive effects on online mathematics learning. Most studies reported gains in achievement, engagement and confidence. The technologies used included intelligent tutoring systems, adaptive learning platforms, fuzzy logic–based systems and AI-supported analytics. Although these tools vary in design, their core purpose is similar: providing personalised support and guiding learners through mathematics content in a more responsive way.

3.1 Overview of the Studies

The studies mainly came from East Asia, North America and Europe, with most focusing on upper primary and secondary mathematics. A smaller number explored undergraduate mathematics, including calculus, pre-algebra and statistics. The research designs ranged from quasi-experimental studies to classroom trials and case studies, reflecting a growing but still developing evidence base.

3.2 AI and Adaptive Technologies Used

Across the studies, four main categories of technologies appeared:

- Intelligent tutoring systems, which provide step-by-step guidance and diagnose errors.
- Adaptive learning platforms, such as ALEKS and CogBooks, which adjust pacing and content based on performance data.
- Fuzzy and expert-system approaches, which take both cognitive and affective factors into account.
- AI-driven analytics, used by tutors to identify learning gaps and intervene more effectively.

Overall, these systems helped personalise learning, offering learners a clearer path through mathematics content and supporting mastery.

3.3 Learning Outcomes

Across the technologies examined, three broad outcomes emerged consistently:

- Achievement: Most studies reported improvements in test scores, accuracy, concept mastery or course grades. Learners using adaptive systems tended to progress more steadily and correct errors more effectively.
- Engagement: Time-on-task, completion rates and voluntary practice were higher when adaptive systems were integrated into online courses.
- Affective factors: Some studies reported lower mathematics anxiety and improved confidence, particularly when systems included affective components such as fuzzy logic or personalised feedback.

Evidence on deeper conceptual understanding was mixed, often depending on the level of scaffolding each system provided.

3.4 Role of Tutors

Although AI systems can automate feedback and provide data-driven insights, the studies show that tutors still play an important role. Learning outcomes were stronger when tutors actively monitored system analytics, clarified automated feedback, provided synchronous support and reinforced key ideas through additional activities. Human facilitation remained essential in helping learners interpret and apply the support provided by AI tools.

3.5 Challenges Identified

The review also highlights several challenges. These include limited transparency in how learner models make decisions, inconsistent data quality, concerns about academic integrity in online assessments and unequal access to devices and stable internet. Most studies were short-term and conducted in school settings, leaving open questions about scalability and relevance to ODDE institutions serving adult or part-time learners.

IV. DISCUSSION

This review shows that AI-driven adaptive technologies can support online mathematics learning in meaningful ways. Across the studies examined, tools such as intelligent tutoring systems, adaptive learning platforms and fuzzy logic–based systems often led to stronger performance, better engagement and greater confidence among learners. These results suggest that AI can help address some of the challenges common in online mathematics environments, including varied learner readiness, difficulties with abstract concepts and the need for more individualised support.

One clear pattern is that AI tools are most effective when used within a well-structured learning design. Systems that personalise pacing, identify misconceptions or offer stepwise guidance work best when they complement established learning activities. This reinforces the idea that AI should enhance—not replace—existing pedagogical practices. It also highlights the importance of alignment between the features of adaptive technologies and the learning goals set by instructors [5].

Across the studies, tutors continued to play a major role in shaping positive learning outcomes. AI systems can automate some forms of support, but they cannot fully replace the judgement, encouragement and responsiveness of a human tutor. Learners often needed clarification, reassurance or additional explanation beyond what automated feedback could provide. When tutors actively monitored analytics, offered targeted feedback and maintained a regular online presence, learners appeared to benefit more. This indicates that successful integration of AI depends not only on the technology itself but also on how tutors understand and use the information it generates.

The review also identifies several areas that require careful attention. Many AI systems rely on learner models that are not always transparent, making it difficult for learners and instructors to understand why certain recommendations or adaptations occur. Data quality and algorithmic fairness remain concerns, especially when systems use performance logs or behavioural indicators to make decisions. In fully online settings, assessment integrity is another recurring issue, particularly when adaptive systems are linked to grading or mastery thresholds.

A further limitation across the literature is the dominance of short-term studies and school-based samples. Much less is known about how AI performs in authentic ODDE environments, where learners are typically adults balancing study with work and family commitments. These learners often enter mathematics courses with varied levels of preparedness and may face technological barriers that school-based studies do not capture. Long-term, real-world investigations are therefore needed to understand how AI tools support retention, reduce anxiety and sustain engagement over time.

Overall, the findings suggest that AI technologies offer promising avenues for supporting learners in online mathematics courses, but their value depends heavily on thoughtful implementation. Clear pedagogical planning, active tutor involvement and attention to issues of access and equity are essential to ensure that AI strengthens—not complicates—the learning experience. As institutions move toward more digitally supported models of teaching, especially in ODDE contexts, there is an opportunity to use these technologies to create more flexible, responsive and personalised mathematics learning environments.

V. IMPLICATIONS FOR ODDE AND OPEN UNIVERSITY CONTEXTS

The evidence in this review aligns well with the needs of open, distance and digital education (ODDE) systems, where learners often study part-time, juggle work and family commitments, and enter with diverse mathematics backgrounds. AI-driven adaptive platforms and intelligent tutoring systems can help by diagnosing misconceptions, individualising practice, and giving learners more control over pace and sequencing. These features fit an ODDE model that values flexibility, self-managed learning, and varied entry points.

At the same time, ODDE institutions tend to enrol large cohorts and rely strongly on part-time tutors. Studies in this review point to the central role of human facilitation in making AI-supported courses effective. Tutors interpret analytics dashboards, respond to patterns in learner errors, and offer socio-emotional support in forums and synchronous sessions. Professional development should therefore focus on helping tutors read and act on AI-generated data, integrate adaptive tasks into coherent course designs, and balance automated feedback with their own pedagogical judgement.

Infrastructure and equity concerns are particularly pressing in ODDE. Many learners connect from rural areas or use older devices, which can limit access to data-intensive platforms. Institution-level planning is needed to select AI tools that work reliably under constrained conditions, provide offline or low-bandwidth alternatives where possible, and embed early technical support. Research in ODDE settings can add value by reporting not only on learning gains, but also on participation patterns, dropout risks, and learners' lived experiences with AI-supported mathematics courses.

For an open university that aims to widen access to mathematics, AI and adaptive technologies should be seen as part of a broader ecosystem that includes clear course structures, responsive tutoring, thoughtful assessment design, and supportive learning analytics policies. When these pieces are aligned, AI can help online mathematics move from a gatekeeping subject towards a more inclusive and supportive learning experience.

VI. CONCLUSION

The studies reviewed show that AI and adaptive technologies can genuinely support learning in online mathematics courses. Tools such as intelligent tutoring systems, adaptive learning platforms and fuzzy logic-based systems helped learners improve their performance, stay engaged and build confidence. These technologies create more personalised pathways, offer timely feedback and give learners chances to work through ideas at a pace that feels manageable.

Across the evidence, one message stands out: AI works best when paired with strong human support. Tutors remain central in helping learners make sense of automated feedback, addressing misunderstandings and creating a space where questions feel welcome. AI may lighten some teaching tasks, but it cannot replace the reassurance, judgement and encouragement that tutors bring into an online classroom.

The review also points to several challenges that deserve attention. Many AI systems still function like "black boxes," making it unclear how decisions or recommendations are made. Data quality varies, and concerns around online assessment continue to surface. Unequal access to devices and stable internet connections further affects how much learners can benefit.

Another key gap is the limited research in open and distance learning environments. Most existing studies focus on school or campus-based settings, leaving unanswered questions about how AI supports adult learners, part-time students, and those studying within flexible ODDE systems. More long-term and real-world studies are needed to understand how these tools fit into the daily realities of distance learners.

Overall, AI holds real promise for making online mathematics learning more personalised and supportive. Its impact, however, depends on thoughtful course design, equitable access and active tutor involvement. With careful planning and ongoing research, AI can contribute to online mathematics environments that feel more encouraging, responsive and accessible for a wide range of learners.

ACKNOWLEDGMENT

The authors gratefully acknowledge colleagues and staff at Open University Malaysia for their encouragement and support during this work.

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AUTHORS

First Author – Assoc Prof Dr Safiah Md Yusof, Faculty of Technology and Applied Sciences, Open University Malaysia
Second Author – Assoc Prof Dr Raziana Che Aziz, Faculty of Technology and Applied Sciences, Open University Malaysia
Third Author – Assoc Prof Dr Alias Mahmud, Faculty of Technology and Applied Sciences, Open University Malaysia
Fourth Author - Ts Sharifah Rosfashida Syed Abd Latif, Faculty of Technology and Applied Sciences, Open University Malaysia
Fifth Author - Dr P. Rajesh Kumar, Faculty of Technology and Applied Sciences, Open University Malaysia

Correspondence Author – Assoc Prof Dr Safiah Md Yusof, safiah_mdyusof@oum.edu.my,