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Research Article:

Co-Teaching with AI: Shift Pedagogy, Opportunities, and Challenges in Mathematics Education

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ABSTRACT

The growing use of artificial intelligence (AI) in education has shifted attention from technology adoption to changes in teaching practice, particularly in mathematics classrooms where instruction depends on diagnosis of misconceptions, responsive support, and pedagogical decision-making. Although existing studies report benefits such as personalised learning, real-time feedback, adaptive instruction, and support for lesson design, they also identify concerns related to teacher agency, curriculum alignment, preparedness, and ethics. Yet this literature remains fragmented, with limited synthesis of how AI functions within teaching processes. This study addressed that gap through a PRISMA-guided systematic literature review of 31 studies published between 2022 and 2025, identified through Scopus, Web of Science, ERIC, and Google Scholar. The included studies covered varied contexts and research designs and were analysed using thematic synthesis. Coding and interpretation were organised around four dimensions: pedagogical shifts, instructional opportunities, implementation challenges, and ethical concerns. The review found that AI is increasingly positioned as a teaching support that influences how teachers plan, adapt, and mediate instruction. Across the studies, teachers were described as taking on expanded roles in facilitating learning, coordinating AI-supported activities, interpreting student data, and monitoring the appropriateness of AI-generated outputs. AI was associated with opportunities for more responsive and differentiated instruction, but these were shaped by teacher readiness, pedagogical fit, and institutional support. The review also identified continuing challenges related to over-reliance, workload, limited contextual flexibility, bias, privacy, transparency, and accountability.

Keywords: Artificial intelligence, co-teaching, secondary mathematics education, systematic literature review, teacher professionalism

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INTRODUCTION

The rapid expansion of artificial intelligence (AI) in education has intensified a global debate that is no longer merely about technology adoption, but about how teaching itself is being reconfigured. Across international scholarship, AI is increasingly positioned not only as a support tool for efficiency, but as an active presence in feedback, assessment, lesson planning, and instructional decision-making (Akgun & Greenhow, 2022; Holmes & Tuomi, 2022; Williamson et al., 2023). This development is especially significant in secondary mathematics education, where teaching involves more than content delivery. Mathematics teachers must interpret students' reasoning, diagnose misconceptions, scaffold conceptual understanding, and make responsive instructional decisions in real time. As intelligent tutoring systems, adaptive platforms, predictive analytics, and generative AI tools become more visible in mathematics classrooms, the critical issue is no longer whether AI can be used, but how it reshapes pedagogical authority, professional judgement, and accountability in practice (Liu et al., 2022; Niloy et al., 2025; Roschelle et al., 2020).

Existing literature points to substantial potential in AI-supported teaching. Studies have associated AI with personalised learning, adaptive pacing, real-time feedback, and more data-informed forms of instructional support, particularly in mathematics where learners often require differentiated pathways and timely intervention. Research also suggests that teacher-AI collaboration may strengthen instructional responsiveness by helping teachers detect learner variation more quickly and adapt teaching with greater precision. However, the literature also reveals persistent tensions. AI may enhance pedagogical flexibility, yet it may also narrow teacher agency when automated recommendations are trusted uncritically or when computational efficiency overrides educational meaning (Perrotta & Selwyn, 2020; Selwyn, 2022). These contradictions suggest that AI in mathematics education should not be understood simply in terms of benefits and barriers, but as a reorganisation of professional work.

Existing studies have identified important barriers to meaningful AI integration, including curriculum misalignment, limited teacher preparedness, increased checking and adaptation work, and uneven institutional capacity (Chiu et al., 2023). At the same time, ethical concerns related to bias, privacy, transparency, surveillance, and academic integrity have raised further questions about the use of AI in classrooms, particularly when teachers remain responsible for decisions shaped by opaque systems (Sun & Zhang, 2023). However, this literature remains fragmented across technological applications, educational levels, and outcome categories. What remains insufficiently understood is how these pedagogical, implementation, and ethical tensions interact when AI is positioned not merely as a tool but as a co-teaching presence in secondary mathematics classrooms. To address this gap, the present study undertakes a PRISMA-guided systematic literature review of studies published between 2022 and 2025 on AI-supported co-teaching in secondary mathematics education. By examining pedagogical shifts, instructional opportunities, implementation challenges, and ethical concerns within a single analytical frame, the review offers a more integrated account of AI-supported teaching in secondary mathematics.

LITERATURE REVIEW

The growing use of AI in education has shifted scholarly attention from the question of whether AI can be adopted in classrooms to how it is shaping teaching and learning processes. In mathematics education, this shift is particularly significant because teaching extends beyond content delivery to include diagnosing misconceptions, supporting reasoning, and adapting instruction to diverse learner needs. Recent scholarship indicates that AI is becoming increasingly embedded in mathematics instruction through adaptive systems, intelligent tutors, predictive analytics, and generative tools that support planning, feedback, and student engagement (Akgun & Greenhow, 2022; Holmes & Tuomi, 2022; Liu et al., 2022; Niloy et al., 2025). These developments suggest that AI is no longer viewed solely as a supplementary technical resource, but as a more active presence within instructional processes, especially in contexts where students require timely guidance and differentiated support. However, the literature remains uneven in its emphasis. Much of the existing work focuses on adoption, acceptance, or effectiveness, while offering less sustained attention to the broader pedagogical implications of AI-supported teaching in secondary mathematics classrooms.

A recurring concern in the literature relates to teacher role and professional agency under AI-supported conditions. Teachers are increasingly described as facilitators, coordinators, and decision-makers who must interpret AI-generated outputs, align them with curriculum goals, and determine their instructional value in practice. In mathematics classrooms, where conceptual explanation and targeted scaffolding are central to effective teaching, this role remains especially important because AI-generated recommendations cannot be applied uncritically (Liu et al., 2022). At the same time, the literature presents competing interpretations of this shift. Some studies suggest that AI can strengthen teaching by extending diagnosis, feedback, and lesson preparation, thereby supporting more flexible instructional decisions. Other studies caution that growing reliance on automated suggestions may constrain teacher judgement. and reduce opportunities for reflective decision-making (Williamson et al., 2023; Perrotta & Selwyn, 2020; Selwyn, 2022). The issue, therefore, is not only that teacher roles are changing, but that the conditions under which teachers exercise professional judgement are also being reshaped.

The literature also identifies a range of instructional opportunities associated with AI, including personalised learning, real-time feedback, adaptive pacing, and more efficient lesson support, particularly in mathematics where students often benefit from differentiated pathways and timely correction of errors (Roschelle et al., 2020). Generative AI has further extended these possibilities by enabling teachers to produce explanations, examples, and tasks with greater flexibility (Niloy et al., 2025). Yet these opportunities are accompanied by persistent implementation and ethical concerns. Studies report curriculum misalignment, increased checking and adaptation work, limited teacher preparedness, and uneven institutional capacity as major constraints on meaningful integration (Chiu et al., 2023). Ethical issues related to bias, privacy, transparency, surveillance, and academic integrity further complicate classroom use, especially when teachers remain accountable for decisions influenced by opaque systems (Sun & Zhang, 2023; Lin et al., 2023). Although these issues are widely acknowledged, they are often examined separately, with limited attention to how instructional opportunities, implementation tensions, and ethical concerns intersect within AI-supported teaching in secondary mathematics education. Taken together, the literature points to the need for a more integrated understanding of AI-supported teaching in secondary mathematics classrooms. This review responds to that need by examining how pedagogical shifts, instructional opportunities, implementation challenges, and ethical concerns are represented across recent studies.

METHODOLOGY

Research Design

This study employed a PRISMA-guided Systematic Literature Review (SLR) to synthesise 31 studies published between 2022 and 2025 that examined AI-supported teaching, teacher-AI collaboration, and associated pedagogical, implementation, and ethical issues across mathematics and related educational contexts, while maintaining secondary mathematics education as the central analytical focus. The PRISMA framework provided a transparent and systematic structure for identifying, screening, assessing eligibility, and selecting studies according to predefined inclusion criteria, thereby enhancing methodological rigor, reducing selection bias, and supporting replicability. The review was undertaken in response to the fragmented and rapidly expanding nature of research on AI in education, particularly within mathematics teaching and learning. This study was designed to be an interpretive and analytical synthesis. Beyond mapping the existing literature, it also examines how AI is conceptualised and enacted as a pedagogical collaborator in secondary mathematics classrooms. The analysis focused on four interrelated dimensions: pedagogical shifts, instructional opportunities, implementation challenges, and ethical considerations. These dimensions were progressively developed and refined through iterative analysis. By systematically consolidating evidence across diverse empirical traditions, the review provides a critical account of the emerging roles of AI in mathematics education and offers insights relevant to future research, teacher development, and policy on the ethical and effective integration of AI in classroom practice.

Data Collection

A total of 31 studies published between 2022 and 2025 were selected from Scopus, Web of Science, ERIC, and Google Scholar using predefined inclusion and exclusion criteria. The review prioritised peer-reviewed studies that addressed AI in instructional or co-teaching roles within secondary mathematics education. The inclusion of quantitative, qualitative, mixed-methods, and systematic review studies enabled methodological triangulation and strengthened the breadth of evidence considered. Each study was assigned a unique identifier (A1–A31) and documented in a structured data extraction matrix. Extracted details included publication information, research design, methodological approach, and findings relevant to AI-supported pedagogy. Indexing status and H-index were also recorded to describe the academic profile of the included sources, although the analysis focused primarily on their conceptual and pedagogical relevance rather than bibliometric standing. Data collection was conducted iteratively. As screening progressed, the inclusion criteria were applied carefully to distinguish studies specifically addressing AI-supported co-teaching or collaborative instructional roles from broader AI-in-education research. This process ensured that the final dataset was both methodologically robust and conceptually aligned with the purpose of the review. Table 1 presents the article codes, source details, indexing status, and h-index of the included studies.

Table 1. Article code, article name, publication type, index and h-index

Code	Article name	Journal/Research paper/Book	Indexed	h-index
A1	Developing a Model for Utilizing Generative AI in Project-Based Learning within Teacher Preparation Programs	International Journal for Research in Education	Scopus	9
A2	Empowering Education through Generative AI: Innovative Instructional Strategies for Tomorrow's Learners	International Journal of Business, Law, and Education	Google Scholar	3
A3	A Framework for Approaching AI Education in Educator Preparation Programs	The Thirty-Eighth AAAI Conference on Artificial Intelligence (AAAI-24)	Scopus	76
A4	Preparing Educators to Teach and Create with Generative Artificial Intelligence	Canadian Journal of Learning and Technology	Scopus	17
A5	A Human-Centered Learning and Teaching Framework Using Generative AI for Self-Regulated Learning	IEEE Transactions on Learning Technologies	Scopus (IEEE)	128
A6	Enhancing Instructional Design: The Impact of CONALI Ontology and ChatGPT in Primary Education Training	ResearchGate/Working Paper	Google Scholar	5
A7	Artificial Intelligence in Mathematics Education: A Systematic Literature Review	International Electronic Journal of Mathematics Education	Scopus, ERIC	29
A8	Integrating Generative AI in University Teaching and Learning: A Model for Balanced Guidelines	Online Learning Journal	Scopus	43

(Continued on next page)

Table 1. *(Continued)*

Code	Article name	Journal/Research paper/Book	Indexed	h-index
A9	Empowering Mathematics Education in Greek Primary Schools through ICT Integration	European Journal of Education and Pedagogy	Google Scholar	6
A10	AI and Data Literacy: Challenges and Opportunities for Teachers and Students	European Journal of Education and Pedagogy	Scopus	43
A11	The Role of Artificial Intelligence in Teaching and Learning in Higher Education: A Systematic Literature Review	Education and Information Technologies	Scopus, Web of Science	63
A12	Artificial Intelligence in Education: Addressing Ethical Challenges in AI Implementation	AI and Ethics	Scopus, Web of Science	15
A13	AI in Education: Exploring the Potential for Teaching and Learning	AI and Society	Scopus, Web of Science	33
A14	Artificial Intelligence Applications in Teaching: Current Trends and Future Prospects	Education and Information Technologies	Scopus, Web of Science	63
A15	The Promises and Challenges of Artificial Intelligence for Teachers: a Systematic Review of Research	TechTrends	Scopus	35
A16	EvoLogic: Toward an ITS for Teaching Propositional Logic	International Journal of Artificial Intelligence in Education	Scopus	43
A17	Investigating the Impact of Backward Strategy Learning in a Logic Tutor: Aiding Subgoal Learning Towards Improved Problem Solving	International Journal of Artificial Intelligence in Education	Scopus	43
A18	The Dynamics of Brazilian Students Emotions in Digital Learning Systems	International Journal of Artificial Intelligence in Education	Scopus	43
A19	Investigating the Impact of Backward Strategy Learning in a Logic Tutor: Aiding Subgoal Learning Towards Improved Problem Solving	International Journal of Artificial Intelligence in Education (IJAIED)	Scopus, Web of Science Springer Link	57

(Continued on next page)

Table 1. *(Continued)*

Code	Article name	Journal/Research paper/Book	Indexed	h-index
A20	The Dynamics of Brazilian Students' Emotions in Digital Learning Systems	International Journal of Artificial Intelligence in Education (IJAIED)	Scopus, Web of Science Springer Link	57
A21	Developing AI Literacy in Secondary Mathematics Education	Journal of Mathematics Education Research	Scopus	15
A22	AI-Enhanced Inquiry-Based Learning in Graphing Concepts	STEM Education Innovations Journal	Scopus	12
A23	Artificial Intelligence in Teaching Graphing Concepts in STEM Classrooms	AI and Education: A Global Perspective (Book Chapter)	Google Scholar	6
A24	Enhancing Mathematics Instruction Through AI Integration	International Journal of STEM Education	Scopus	22
A25	Application of Generative AI in K-12 STEM Teaching Practices	International Journal of Educational Technology	Scopus	18
A26	Bringing Teachers in the Loop: Exploring Perspectives on Integrating Generative AI	International Journal of Artificial Intelligence in Education	Scopus	33
A27	Systematic Review of Research on AI Applications in Higher Education	International Journal of Educational Technology in Higher Education	Scopus	41
A28	STEM Teacher Perceptions, Familiarity, and Support Needs for Integrating GenAI	School Science and Mathematics	Wiley/ Google Scholar	24
A29	Transforming Education: Exploring the Influence of Generative AI on Teaching Performance	Cogent Education	Taylor & Francis/ Scopus	28
A30	Predictive AI and Graphing Instructional Tools in High School Settings	Journal of Educational Data Science	Scopus	10
A31	Artificial Intelligence-Supported Learning Environments in Mathematics Education	Education and Information Technologies	Scopus, Web of Science	63

The collection of data from these 31 articles provides a robust foundation for understanding the pedagogical shifts, technological advancements, and implementation challenges associated with AI in education. It reflects a growing body of interdisciplinary research committed to transforming teaching and learning through innovative, data-driven approaches.

VALIDITY AND RELIABILITY

The trustworthiness of this review was established through a rigorous PRISMA-guided process that ensured transparency in the identification, screening, eligibility assessment, and final selection of 31 peer-reviewed studies. Content validity was strengthened through a comprehensive search across Scopus, Web of Science, ERIC, and Google Scholar, together with clearly defined inclusion and exclusion criteria aligned with the review focus. Credibility was enhanced through methodological triangulation, as the dataset included quantitative, qualitative, mixed-methods, and review-based studies, enabling the synthesis of diverse forms of evidence and educational perspectives. Dependability was supported by the use of a structured data extraction matrix that recorded study context, design, participants, AI application, key findings, and limitations, thereby allowing each code and theme to be traced back to its original source. Conflicting findings were compared systematically across study contexts and designs. For example, studies reporting improved feedback and instructional support through AI were examined alongside those highlighting increased workload, over-reliance, and limited pedagogical fit. Theme boundaries were determined through iterative comparison of coded data, so that analytically distinct categories were not collapsed prematurely; for instance, instructional opportunities were distinguished from implementation challenges when studies showed clear pedagogical potential but practical limitations in classroom use. Confirmability was reinforced through explicit documentation of interpretive decisions, including the development of codes, refinement of themes, and treatment of contradictory evidence. Collectively, these procedures strengthened the credibility, dependability, confirmability, and replicability of the review.

DATA ANALYSIS

Data were analysed using a multi-stage thematic synthesis designed to generate interpretive insights. The dataset comprised studies employing quantitative, qualitative, mixed-methods, systematic review, design-based, and case-based approaches, allowing patterns to be examined across diverse methodological traditions. The analysis began with open coding. Each article was read in full, and relevant meaning units were inductively coded in relation to teacher roles, instructional practices, technological affordances, implementation constraints, and ethical concerns. A structured coding matrix was used to ensure consistency across studies, while constant comparison enabled the researcher to examine similarities, variations, and contradictions in how AI was conceptualised and enacted. Codes were revised, merged, and expanded iteratively as the analysis developed.

The identified codes then were grouped into broader conceptual categories through axial coding and then refined into higher-order themes. Theme refinement involved comparing findings across studies, abstracting underlying concepts, and clarifying thematic boundaries so that each theme was analytically distinct yet conceptually related to the overall framework. Through this process, four themes were developed: pedagogical shifts, instructional opportunities, implementation challenges, and ethical considerations. Interpretation proceeded through an interpretive synthesis approach, focusing not only on what studies reported but also on how and why particular findings emerged across contexts. This enabled the review to identify deeper patterns concerning the reconfiguration of teacher roles, the conditional nature of AI-related benefits, and the contextual factors shaping implementation. Contradictory findings were treated as analytically significant and examined in relation to differences in setting, tool type, teacher expertise, and research design. By incorporating such variation into the synthesis, the review moved beyond confirmatory description and produced a more nuanced account of AI-supported co-teaching in secondary mathematics education.

Collectively, this analytical process showed that while AI offers opportunities for differentiated learning, real-time feedback, and enhanced instructional design, its effectiveness remains closely tied to teacher readiness, pedagogical alignment, and ethical safeguards. The analysis therefore highlights the need for evidence-based teacher preparation, pedagogical flexibility, and robust ethical frameworks to support meaningful AI integration in mathematics classrooms.

RESEARCH PROCEDURE

This systematic literature review was conducted through a PRISMA-guided five-phase procedure to ensure transparency, consistency, and analytical rigor in the identification, selection, and synthesis of studies on AI-supported co-teaching in secondary mathematics education.

Phase 1: Search Strategy Development

A systematic search was conducted across four established academic databases, namely Scopus, Web of Science, ERIC, and Google Scholar, chosen for their broad coverage of educational technology, pedagogy, and interdisciplinary research. The search was limited to studies published between January 2022 and May 2025 in order to capture recent developments related to the rapid expansion of generative and intelligent AI tools in educational settings. Search strings were developed and adapted across databases using combinations of terms related to artificial intelligence, co-teaching, teacher–AI collaboration, secondary mathematics education, and pedagogy. This search process yielded 18,719 records, comprising 16,262 records from databases and 2,457 from additional sources.

Phase 2: Screening and Eligibility Assessment

After duplicates were removed, 13,114 records remained for screening. Titles and abstracts were reviewed to determine their relevance to AI-supported co-teaching in secondary mathematics education. At this stage, 12,590 records were excluded because they did not sufficiently address pedagogical collaboration with AI, mathematics teaching, or instructional applications aligned with the focus of the review. Subsequently, 524 full-text articles were retrieved and assessed using predefined inclusion and exclusion criteria. Studies were included if they were peer-reviewed, published between 2022 and 2025, written in English, accessible in full text, and reported empirical evidence on AI in instructional roles within secondary mathematics education. Studies were excluded if they focused on non-secondary contexts, lacked pedagogical relevance, were theoretical or opinion-based, did not report empirical data, or failed to reflect a co-teaching or collaborative instructional orientation. Following this process, 493 studies were excluded, leaving a final dataset of 31 studies for analysis. Figure 1 shows how PRISMA was used to select all 31 peer-reviewed articles.

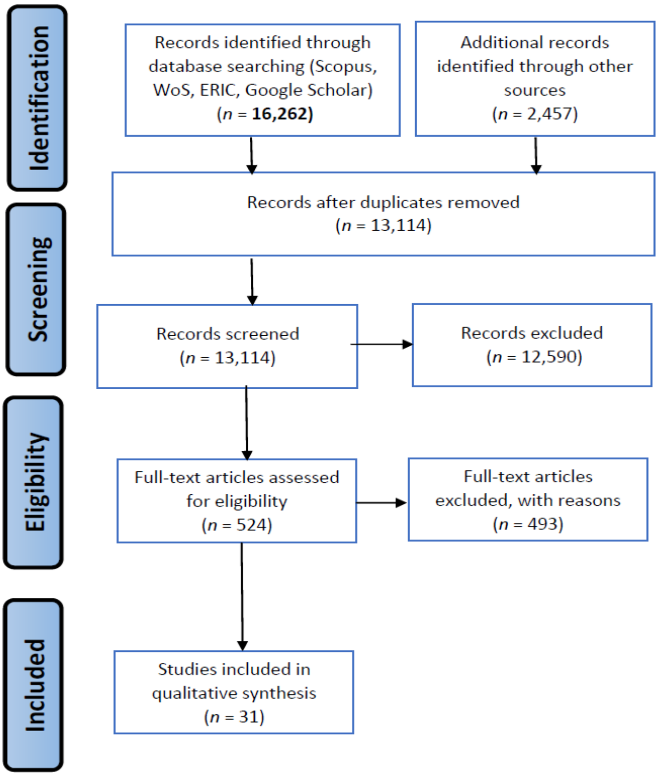

Figure 1. Stages of the review process

Phase 3: Data Extraction

The 31 selected studies were entered into a structured data extraction matrix to ensure consistency and traceability throughout the review. Extracted information included publication details, methodological approach, research design, educational context, type of AI application, and findings related to pedagogy, implementation, and ethics. This matrix served not only as a record of study characteristics but also as an analytical tool to support systematic comparison across studies.

Phase 4: Coding and Theme Development

Each study was read in full and inductively coded to identify meaning units related to teacher roles, instructional practices, technological affordances, implementation constraints, and ethical concerns. Coding was conducted iteratively, with constant comparison used to examine similarities, variations, and tensions across studies. Related codes were then grouped into broader conceptual categories and progressively refined into four higher-order themes: pedagogical shifts, instructional opportunities, implementation challenges, and ethical considerations. These themes were not imposed in advance but were developed through repeated engagement with the data to ensure that the analysis moved beyond descriptive categorisation towards conceptual interpretation.

Phase 5: Interpretive Synthesis

The final phase involved interpretive synthesis, in which the analysis focused not only on what the studies reported, but also on how and why findings differed across contexts. Attention was given to variations in research design, educational setting, type of AI tool, and the level of teacher readiness or pedagogical support described in each study. Contradictory findings were treated as analytically meaningful rather than problematic. For example, studies reporting that AI reduced teacher workload were examined alongside studies indicating increased workload, and these differences were interpreted in relation to implementation conditions, technological complexity, and pedagogical alignment. By retaining and analysing such contradictions, the review produced a more nuanced and critically grounded account of AI-supported co-teaching in secondary mathematics education.

FINDINGS

Theme 1: Methodological Approach

As shown in Figure 2, the reviewed studies reflect a diverse methodological distribution. A clear methodological pattern across the 31 reviewed studies is that the field is diverse in design but uneven in analytical maturity. The evidence base includes empirical inquiry, qualitative and quantitative studies, systematic reviews, design-oriented work, and ethical or conceptual papers, showing that AI-supported teaching is being examined through multiple complementary lenses. However, mixed-method and review-oriented studies remain particularly prominent, suggesting that the literature is currently stronger at identifying emerging uses, perceptions, and implementation issues than at explaining how teacher–AI collaboration becomes sustained pedagogical practice over time.

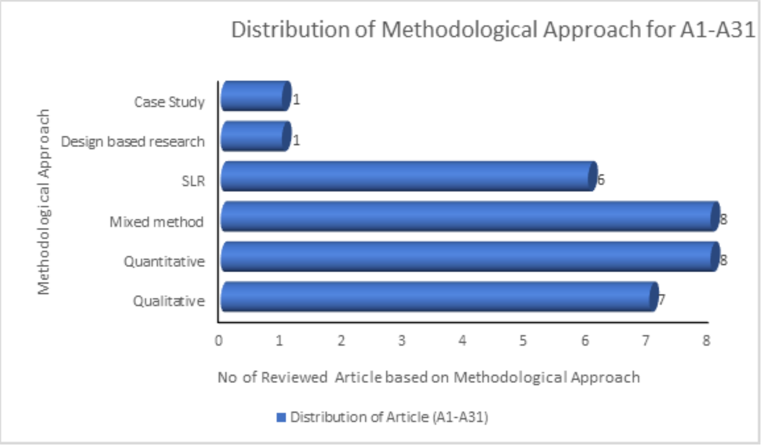

Figure 2. Methodological approach and number of articles

This pattern is visible in the contrast between empirical classroom and perception-focused studies such as A1, A3, A4, A21, A24, A25, A28, A29, A30, and A31, which foreground implementation and teacher response, and review-oriented or conceptual studies such as A7, A11, A15, A10, A12, and A13, which focus more strongly on recurring pedagogical, ethical, and governance issues. Read together, these clusters show that the field is not methodologically weak, but developmentally uneven: it documents adoption well, yet still offers limited longitudinal and theory-building insight into how AI reshapes teacher professionalism in mathematics education. Overall, the reviewed literature suggests that research on AI co-teaching in mathematics is expanding rapidly, but its evidence base remains more exploratory than developmentally mature.

Theme 2: Co-Teaching with AI: Pedagogical Shifts, Opportunities, Challenges, and Ethical Concerns

Across the reviewed studies, the most important finding is not that AI introduces separate benefits and risks, but that it redistributes the work of teaching. In both mathematics-focused studies and broader AI-in-education studies, AI repeatedly appears as a source of support for feedback, personalisation, and instructional design while simultaneously increasing demands on teachers to interpret outputs, align them with curriculum and pedagogy, manage implementation tensions, and remain accountable for ethical consequences. This broader pattern suggests that AI co-teaching in mathematics is best understood not as a straightforward extension of instructional efficiency, but as a reorganisation of professional work. The significance of this shift lies in the fact that efficiency gains are inseparable from new demands on judgement, coordination, and responsibility.

Theme 2a: Pedagogical Shifts

As illustrated in Figure 3, the reviewed studies show a clear distribution of teacher roles in AI co-teaching across the 31 articles. The strongest pedagogical shift across the reviewed studies is not simply that teachers take on more roles, but that teacher expertise moves from delivery toward mediation.

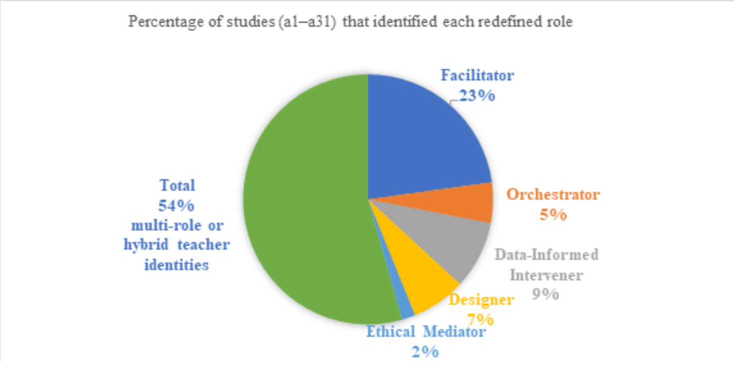

Figure 3. Redefined teacher roles in AI co-teaching environments

The roles of facilitator, orchestrator, data-informed intervener, designer, and ethical mediator should be interpreted not as separate teacher types, but as interconnected expressions of a broader shift in teacher professionalism under AI-supported conditions. Across studies such as A21, A22, A24, A30, and A31, and more broadly A10, A15, and A29, teachers were required not only to support learning, but also to interpret AI outputs, coordinate their use, and judge their pedagogical and ethical appropriateness. This extends existing pedagogical frameworks by showing that teaching with AI involves more than delivery, facilitation, or assessment alone; it requires ongoing mediation between algorithmic support and educational purpose. At the same time, it challenges conventional professional identity frameworks by suggesting that teacher authority increasingly rests not only on subject expertise, but also on data literacy, adaptive decision-making, and ethical stewardship. Taken together, these findings indicate that AI reconfigures, rather than replaces, teacher professionalism in mathematics education.

Theme 2b: Instructional Opportunities

As shown in Table 2, the reviewed studies identify the main instructional opportunities enabled by AI and their relative proportions. The strongest instructional pattern across the reviewed studies is that AI improves the responsiveness of teaching more than it automates teaching.

Table 2. Instructional opportunities and coding

Opportunity category	AI functionality	Observed teacher outcomes	Illustrative studies	Proportion of studies (%)
Personalised Learning	Adaptive content generation	Increased student engagement, differentiated pacing, and learner autonomy	A1–A3, A14, A21, A30	28
Automated Feedback	Real-time grading, error detection, and progress tracking	Reduced marking time, enhanced formative feedback quality, and timely error correction	A6, A15, A18, A25	21
Data-Driven Instruction	Predictive analytics, performance dashboards	Proactive intervention, early identification of learning gaps, and evidence-based teaching	A4, A5, A20, A23	19
Differentiation Support	Grouping algorithms, scaffolding tools, and adaptive difficulty adjustment	Improved inclusion for diverse learners and targeted support for low achievers	A16, A17, A24, A26	17
Creative Lesson Design	Generative AI for co-creation of teaching materials and simulations	Increased instructional efficiency, innovative lesson planning, and creative engagement	A8–A13, A31	15

The instructional opportunities identified across the review, particularly personalisation, automated feedback, data-informed support, and lesson design, are analytically connected as forms of enhanced pedagogical responsiveness. Rather than functioning as isolated advantages, they collectively enable teachers to notice learner variation more quickly, respond more strategically, and adapt instruction with greater precision. This pattern is evident in studies such as A1, A3, A21, and A30, where AI supported misconception detection and tailored pacing, and in A6, A15, A18, and A25, where automated feedback reduced routine checking and enabled quicker follow-up. Overall, the instructional value of AI in mathematics co-teaching lies not in autonomous instruction, but in strengthening teachers' adaptive and interpretive capacity.

Theme 2c: Challenges in Implementation

As shown in Figure 4, the reviewed studies highlight several major implementation challenges, with over-reliance on AI emerging as the most frequently reported issue across nine studies. The strongest implementation pattern across the reviewed studies is a mismatch between computational efficiency and pedagogical fit.

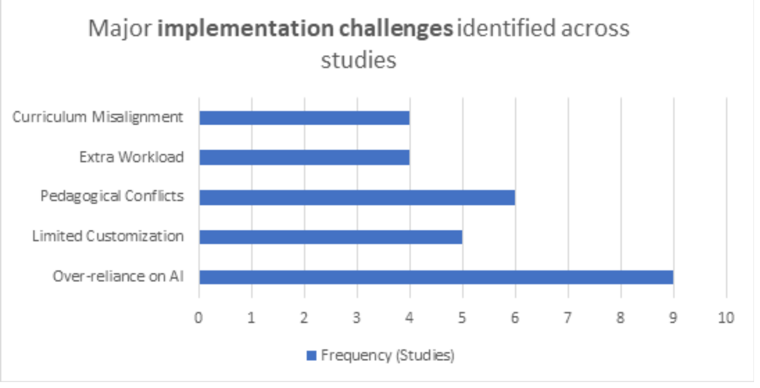

Figure 4. Key challenges in implementing AI-enabled co-teaching across 31 reviewed studies

AI systems often appear attractive because they are fast, scalable, and able to generate feedback or content efficiently, but these same features become problematic when they privilege procedural output over conceptual understanding or fail to align with curriculum, language, and classroom realities. This tension is visible, for example, in studies such as A5, A10, A14, A15, A24, A26, A28, A29, and A31, where over-reliance on AI risked displacing reflective teacher judgement., and in A7, A12, A13, A21, A22, A23, A24, A30, and A31, where AI-generated tasks, examples, or explanations often required substantial modification before they could be meaningfully used in local mathematics classrooms. Rather than representing isolated technical problems, these challenges point to a deeper structural tension between computational optimisation and educational meaning. Taken together, the findings suggest that the central implementation challenge in AI co-teaching is not technology access itself, but preserving pedagogical integrity and teacher agency within systems designed primarily for efficiency.

Theme 2d: Ethical Concerns

As shown in Figure 5, the reviewed studies and the researcher's coding reveal the main ethical concerns associated with AI co-teaching. The strongest ethical pattern across the reviewed studies is that AI redistributes responsibility in teaching. Bias, privacy, transparency, academic integrity, and relational concerns are best understood not as separate issues, but as connected expressions of a wider accountability problem: the more

AI shapes instructional decisions, the harder it becomes to determine who is answerable for fairness, trust, and legitimacy in classroom practice.

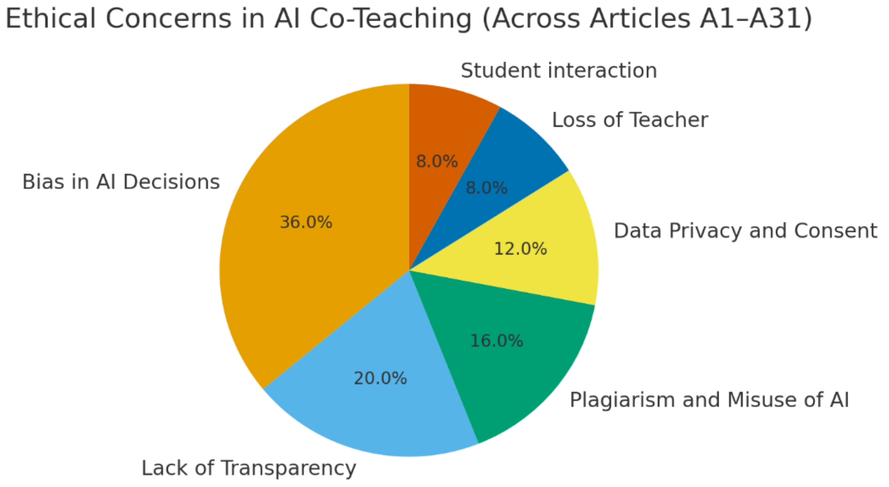

Figure 5. Ethical concerns in AI co-teaching

This pattern is especially visible in ethical and conceptual studies such as A10, A11, A12, A13, A15, A26, A27, A28, and A29, and it is reinforced in mathematics-related studies such as A21, A24, A30, and A31, where teachers had to judge the trustworthiness and fairness of AI-supported decisions in practice. Analytically, this means that ethics is not an external add-on to implementation; it is part of teacher professionalism itself. AI-mediated teaching requires teachers not only to use digital tools, but also to remain visibly accountable for how those tools shape learning, participation, and judgement. Overall, the central ethical issue in AI co-teaching in mathematics is the need to preserve human accountability in increasingly data-driven and opaque instructional environments.

Integrated Interpretation of the Findings

Themes 1 and 2 indicate that the significance of AI co-teaching in mathematics lies less in technological substitution than in the reorganisation of teacher professionalism. Although the reviewed evidence remains more exploratory than longitudinal, a shared pattern is already visible: AI expands instructional possibilities while simultaneously increasing demands on teachers to interpret outputs, preserve pedagogical meaning, and remain accountable for fairness and trust. Overall, the findings suggest that AI-supported teaching is most appropriately understood as a shift toward more interpretive, context-sensitive, and ethically mediated forms of professional practice.

DISCUSSION

This systematic literature review was undertaken in response to a persistent gap in the global literature: although artificial intelligence (AI) is increasingly discussed as a powerful educational technology, there is still limited conceptual clarity about what changes when AI functions not merely as a tool, but as a co-teacher in secondary mathematics classrooms (Akgun & Greenhow, 2022; Niloy et al., 2025). Across the 31 studies reviewed, the discussion points to a consistent conclusion: the significance of AI in mathematics education lies less in automating instruction than in reorganising teacher professionalism. Rather than confirming a simple narrative of benefit or disruption, the review shows that AI simultaneously expands pedagogical possibilities and intensifies demands for teacher interpretation, coordination, and ethical judgement. Artificial intelligence integration in education not only reshapes pedagogical practices but also enhances teachers' technological and instructional competencies (Sun et al., 2023), while raising critical concerns related to data, power, and ethics (Macgilchrist, 2023). Technology-enhanced approaches such as augmented reality further demonstrate the potential of pedagogical innovation in bridging learning inequalities (Lin et al., 2023). This reframes co-teaching with AI as a pedagogical and professional reconfiguration rather than as a technical innovation alone, extending arguments that AI changes teacher agency, instructional decision-making, and the conditions under which professional authority is exercised in classrooms (Williamson et al., 2023).

Reconfiguring Teacher Professionalism under AI Co-Teaching

One of the most important contributions of this review is the identification of a shift in teacher expertise from delivery toward mediation. The roles of facilitator, orchestrator, data-informed intervener, designer, and ethical mediator are not best understood as separate teacher types, but as interconnected expressions of how teaching is being redefined under AI-supported conditions (Zhao et al., 2022). This finding extends existing pedagogical discussions by showing that teaching with AI is not limited to facilitation, assessment, or classroom management in their conventional forms. Instead, it requires teachers to interpret algorithmic outputs, coordinate the relationship between human judgement and machine-generated recommendations, and decide when those recommendations are pedagogically valid, contextually appropriate, and ethically defensible. This also challenges more traditional professional identity frameworks in which teacher authority is grounded primarily in subject expertise and classroom delivery. The reviewed studies suggest that authority in AI-mediated classrooms increasingly depends on data literacy, adaptive decision-making, and ethical stewardship (Xie & Luo, 2025). In this sense, the review moves beyond confirmatory claims that teachers remain "important" in AI-supported settings. More specifically, it shows why they remain central: not because AI cannot perform instructional tasks, but because only teachers can integrate those tasks into educationally meaningful, socially legitimate, and context-sensitive practice (Williamson et al., 2023; Selwyn, 2022). This is especially significant in secondary mathematics education, where correct answers, rapid feedback, and adaptive pacing may appear pedagogically useful, yet still require teacher judgement. to ensure conceptual understanding, curricular coherence, and fairness (Liu et al., 2022; Roschelle et al., 2020).

From Automation to Pedagogical Responsiveness

A second major contribution of the review is the finding that the most meaningful instructional opportunities created by AI are forms of enhanced pedagogical responsiveness. Personalisation, automated feedback, data-informed support, and lesson design should not be treated as isolated advantages. Rather, they work together by helping teachers notice learner variation earlier, respond more strategically, and adapt instruction more precisely. This is important because much of the public and policy discourse around AI in education still frames its value in terms of efficiency, automation, or labour-saving potential. The reviewed studies suggest a different interpretation. AI is most educationally valuable not when it acts independently of teachers, but when it strengthens teachers' capacity to make more timely and better-informed pedagogical decisions (Niloy et al., 2025; Roschelle et al., 2020).

This insight also helps clarify the originality of the review. Existing literature often celebrates adaptive systems, intelligent tutoring, and automated feedback as evidence that AI can optimise instruction (Liu et al., 2022; Roschelle et al., 2020). However, the synthesis here suggests that optimisation alone is not the core issue. What matters is whether AI enhances teachers' adaptive expertise in ways that remain aligned with mathematical meaning, learner diversity, and classroom purpose (Niloy et al., 2025). In other words, the most substantial opportunity of AI co-teaching is not instructional autonomy, but pedagogical responsiveness. This shifts the conversation from what AI can do on its own to what teachers can do differently when AI is critically and contextually integrated into practice.

Implementation Tensions: Optimisation versus Educational Meaning

The discussion also shows that implementation challenges should not be understood merely as barriers to adoption. Rather, they reveal a deeper tension between the logic of computational optimisation and the logic of pedagogy. AI systems are frequently valued because they are fast, scalable, and capable of generating feedback, tasks, or recommendations efficiently. Yet these same strengths become limitations when they privilege procedural output over conceptual understanding, or when they fail to align with local curriculum, language, assessment structures, and classroom realities (Chiu et al., 2023; Williamson et al., 2023; Perrotta & Selwyn, 2020). This helps explain why over-reliance, pedagogical conflict, curriculum misalignment, limited customisation, and increased workload recur so consistently across the reviewed studies.

This point is analytically important because it moves the discussion beyond the familiar claim that teachers need "more training" to use AI effectively. The review suggests that the challenge is not simply a deficit in teacher skill, but a structural mismatch between systems designed for optimisation and educational practice organised around meaning, progression, and context (Macgilchrist, 2023; Perrotta & Selwyn, 2020). AI can automate certain tasks, but in doing so it often redistributes work into more complex forms of monitoring, interpreting, validating, and redesigning. For this reason, successful integration depends not only on technical support, but on professional development that foregrounds critical data literacy, pedagogical adaptation, and the ability to resist uncritical reliance on algorithmic authority (Xie & Luo, 2025). Globally, this has significant implications for teacher education, because it suggests that AI readiness should be defined not only in technical terms, but also in interpretive and ethical terms.

Ethics as a Pedagogical and Governance Issue

The ethical discussion emerging from the review is similarly more complex than a list of risks. Bias, privacy, transparency, academic integrity, and relational concerns are best understood as connected expressions of a broader accountability problem. The more AI participates in instructional decision-making, the harder it becomes to determine who is answerable for fairness, trust, and legitimacy in classroom practice (Sun & Zhang, 2023). This means that ethics is not an external add-on to implementation; it is part of the pedagogical core of AI co-teaching. This interpretation is consistent with research showing that trust in AI depends not only on system performance, but also on transparency, explainability, and the teacher's capacity to judge when algorithmic outputs should be accepted, questioned, or rejected (Lin et al., 2023).

The reviewed studies further suggest that ethical concerns are mediated by context. In multilingual, exam-oriented, or infrastructure-limited systems, ethical risks often appear through curriculum misfit, linguistic bias, or unequal access. In better-resourced contexts, concerns may shift toward over-surveillance, data commodification, or teacher dependency on analytics (Selwyn, 2022; Sun & Zhang, 2023). This is why universal statements about "ethical AI" are insufficient. Ethical confidence depends not only on system design, but also on governance arrangements, policy protection, institutional support, and local cultural expectations about teaching, authority, and care. For secondary mathematics education, this point is especially important because the apparent precision of AI-generated answers can conceal deeper concerns about bias, opacity, and conceptual distortion. The role of the teacher as ethical mediator is therefore not a peripheral finding; it is one of the review's strongest conceptual insights.

Global Contribution and Research Gaps

This review contributes to international scholarship by shifting attention from AI adoption to AI co-teaching as a question of teacher professionalism, pedagogical judgement, and governance. Rather than asking whether AI can support teaching, the more important issue is under what pedagogical, ethical, and contextual conditions such support remains educationally legitimate and professionally sustainable (Akgun & Greenhow, 2022; Holmes & Tuomi, 2022; Niloy et al., 2025). The review therefore offers important implications for policy and practice, particularly the need for governance frameworks, ethical accountability, and professional development that emphasises adaptive decision-making and critical interpretation of AI.

At the same time, the evidence base remains limited. Although the literature is diverse, it is still largely exploratory and uneven in global coverage (Akgun & Greenhow, 2022). Longitudinal and cross-cultural studies remain scarce, and few studies examine how AI-related professional learning develops into sustained classroom practice over time (Holmes & Tuomi, 2022; Niloy et al., 2025; Xie & Luo, 2025). These gaps point to the need for more comparative, contextual, and long-term research.

Overall, the review suggests that the key issue is not whether AI will replace teachers, but how it reshapes what it means to teach well in mathematics classrooms. AI can broaden teachers' pedagogical possibilities, but only when its use is critically interpreted, contextually aligned, and ethically governed (Perrotta & Selwyn, 2020; Selwyn, 2022; Lin et al., 2023). When positioned as a reflective co-teacher rather than a substitute, AI can support a more responsive, data-informed, and ethically accountable form of practice.

CONCLUSION

This systematic literature review synthesised 31 peer-reviewed studies published between 2022 and 2025 to examine how artificial intelligence is reshaping teaching in secondary mathematics education. The review shows that AI functions not merely as a technological tool, but as a pedagogical force that reconfigures teacher professionalism, instructional practice, and ethical responsibility. While AI-supported co-teaching expands opportunities for personalised learning, adaptive feedback, differentiated instruction, and more responsive lesson design, it also introduces challenges related to over-reliance, curriculum misalignment, contextual inflexibility, increased interpretive workload, and ethical uncertainty.

Overall, the findings suggest that the significance of AI in mathematics education lies less in instructional automation than in the redistribution of teacher work. Rather than replacing teachers, AI shifts teacher expertise toward more interpretive, adaptive, and ethically accountable forms of practice. Its successful integration therefore depends not only on technological advancement, but also on contextual alignment, institutional support, and the strengthening of teachers' pedagogical, data, and ethical literacy. In this sense, co-teaching with AI should be understood as a reorganisation of teacher professionalism, with teachers remaining central to ensuring meaningful, fair, and human-centred learning.

IMPLICATIONS AND RECOMMENDATIONS

The findings have important implications for policy, practice, and research in secondary mathematics education. As AI becomes a pedagogical collaborator rather than just a tool, education systems must address the professional, ethical, and institutional conditions shaping its use. Policy should provide clear guidance on responsible AI integration, including data governance, transparency, curriculum alignment, and teacher autonomy. In practice, effective AI integration depends on teachers' ability to interpret, adapt, and critically evaluate AI outputs. Professional development should therefore go beyond technical skills to include pedagogical use, data literacy, ethical reasoning, and adaptive instructional design. School leaders also play a key role in supporting collaborative and reflective AI use.

The review further suggests that AI tools should be designed in closer partnership with educators so they are explainable, adaptable, and contextually relevant. For research, more longitudinal, comparative, and context-sensitive studies are needed to understand how AI co-teaching shapes teacher practice and student learning over time. Overall, sustainable AI integration depends not only on innovation, but on policies, professional learning, and research that keep pedagogy, ethics, and teacher agency at the centre.

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