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AI-Powered Discourse in Mathematics Education in Support of SDG 4: A Systematic Review of Contemporary Research Literature

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Abstract

This systematic review critically examines contemporary research on the integration of artificial intelligence (AI) in supporting mathematical discourse, with a specific focus on its alignment with Sustainable Development Goal 4 (SDG 4); which advocates for inclusive and equitable quality education. Drawing on 25 peer-reviewed studies published between 2015 and 2025, the review synthesises empirical and theoretical insights into how AI technologies such as natural language processing tools, intelligent tutoring systems, conversational agents and discourse analytics dashboards -transform mathematics education by enhancing student engagement, reasoning and participation. The findings reveal that AI-powered discourse interventions support multiple SDG 4 targets including improving learning outcomes (Target 4.1), promoting equity and inclusion (Target 4.5), and strengthening teacher capacity through professional development (Target 4.c). However, the review also identifies persistent challenges related to technological limitations, ethical concerns surrounding data privacy and algorithmic bias, and the need for extensive teacher training. Geographically, research remains predominant in East and Southeast Asia, North America, and the Middle East, with notable underrepresentation from the Global South. The review concludes by offering strategic recommendations for inclusive AI design, teacher-centred implementation and policy infrastructure that collectively aim to harness AI's potential for fostering equitable and dialogic mathematics learning environments worldwide.

Keywords: artificial intelligence, SDG 4, equity in education, dialogic teaching, educational technology, systematic review.

Introduction

Background and Rationale

The role of discourse in mathematics education is foundational in advancing students' conceptual understanding, reasoning abilities and engagement with

mathematical ideas. Classroom dialogue allows learners to articulate their thought processes, negotiate meaning, and collaboratively construct knowledge—processes that are central to deep mathematical learning, and the development of critical thinking skills (Zreik, 2024; Willie, 2017). These discursive interactions foster environments that promote collaboration and problem-solving, aligning with innovative educational paradigms that seek to move beyond traditional models of instruction toward more interactive and inclusive approaches (Roos, 2023; Brewley-Kennedy, 2016; Heasly et al., 2025). Moreover, mathematical discourse enhances not only subject-specific literacy but ensures that teaching practices resonate with the diverse sociocultural experiences of learners as well; reflecting a growing commitment to equity in educational environments (Maldonado Rodríguez et al., 2022; Aquirre et al., 2017). Discourse enhances mathematical proficiency and serves as a vehicle for developing students' voices and identities within learning communities (Akinci et al., 2025).

Recent developments in online learning and artificial intelligence (AI) present novel opportunities to augment and transform discourse practices in mathematics education (Arugaslan, 2025; Kaynak et al., 2018; Meylani, 2025d; Yıldız & Özkök, 2025). The integration of artificial intelligence (AI) into mathematics education introduces transformative opportunities to support and extend these discursive practices. AI technologies such as natural language processing tools, intelligent tutoring systems and conversational agents—enable individualised feedback and real-time analysis of classroom interactions; thereby augmenting teacher facilitation and scaffolding student discourse (Meylani, 2024; Qothrunnada & Maghfiroh, 2025; Zreik, 2024). Recent advancements have led to the development of AI-driven frameworks capable of evaluating the quality of classroom dialogue, leveraging data analytics to inform pedagogical strategies and improve learning outcomes (Güler & Polatgil, 2025; Li et al., 2025). In addition, AI-supported personalisation mechanisms adapt instructional pathways to accommodate diverse learner profiles, particularly those of students from historically marginalised communities (Alsharidah & Alkramiti, 2024; Roshanaei et al., 2023). These affordances contribute to the transformation of mathematics classrooms into student-centred environments where engagement, inquiry and collaboration are prioritised (Opesemowo, 2024; Hwang & Tu, 2021).

The strategic use of AI in mathematics education aligns with the principles of Sustainable Development Goal 4 (SDG 4), which advocates for inclusive and equitable quality education and lifelong learning opportunities for all. AI technologies offer considerable promise for transforming discourse-rich environments by enabling adaptive feedback, multimodal interaction and individualised learning trajectories. These developments support equitable mathematics instruction in alignment with SDG 4 (Meylani, 2025b; Meylani, 2025a). Meylani (2024) emphasises that sustained professional development grounded in AI-supported environments enhances teachers' instructional decisions and their capacity to foster discourse-oriented practices. AI-powered interventions play a pivotal role in improving learning outcomes (Target 4.1) and narrowing educational disparities (Target 4.5), while simultaneously enhancing teacher capacity through targeted professional development and data-informed insights (Alexander et al., 2024; Viberg et al., 2024; Roshanaei et al., 2023; Tural Sönmez, 2024). This alignment not only advances the digital transformation of education but reinforces the pursuit of social justice within mathematics instruction. When guided by ethical frameworks and inclusive strategies, the implementation of AI affirms a vision of education that is both technologically progressive and socially responsive (Zreik, 2024; Hwang & Tu, 2021).

Gaps in Existing Literature

Despite the promising potential of AI, the current literature indicates substantial gaps in understanding its role in mediating discourse within mathematics classrooms. While many studies have explored the technological affordances of AI or its impact on general learning outcomes, few have examined specific mechanisms through which AI supports equitable and high-quality classroom dialogue (Awang et al., 2025; Qothrunnada & Maghfiroh, 2025: Opesemowo, 2024). This gap underscores the need for a systematic and critical synthesis of research to clarify the affordances and limitations of AI in discourse-oriented instructional practices. Such work is crucial for mapping the dynamic interplay between AI technologies, teacher facilitation, and student interaction, and for understanding how these components should be orchestrated to advance dialogic teaching and equity in mathematics education (Alexander et al., 2024; Li et al., 2024; Roshanaei et al., 2023). Future research should engage with both empirical and theoretical dimensions to establish a comprehensive framework that not only leverages the benefits of AI but ensures its ethical and equitable integration into mathematics classrooms (Alsharidah & Alkramiti, 2024; Maldonado Rodríguez et al., 2022; Hwang & Tu, 2021).

Purpose and Guiding Questions

This systematic review addresses this gap by examining contemporary research on AI-powered discourse in mathematics education. It aims to provide a comprehensive synthesis of how AI technologies are used to support mathematical dialogue, and to evaluate their contributions to advancing SDG 4. The guiding questions for this review are as follows:

- What are the key characteristics of AI-powered discourse interventions in mathematics education?
- How do these interventions support the goals and targets of SDG 4 (e.g., quality, equity, inclusivity)?
- What are the measured impacts of AI on discourse quality, participation, and mathematical reasoning?
- What challenges, limitations and ethical concerns are reported in the implementation of such technologies?

By exploring these questions, this review seeks to build a foundation for informed research, practice, and policy aimed at leveraging AI to support quality mathematics education worldwide.

Conceptual Framework

Theoretical Underpinnings of Discourse in Mathematics Education

Discourse in mathematics education serves as a cornerstone for cultivating deep conceptual understanding, fostering metacognitive development, and supporting collaborative learning processes among students. A central theoretical lens informing this discourse is Sfard's commognitive framework, which reconceptualises mathematical thinking as a form of communication. According to this view, learning occurs through shifts in the patterns and structures of discourse, as students begin to internalise the appropriate specialised language and reasoning of the mathematical community (Bimba et al., 2017). The framework suggests that changes in learners'

discourse signal cognitive development, thus establishing a direct link between communication and thinking (Shahrill et al., 2023).

Complementing this perspective is Vygotsky's sociocultural theory, which frames learning as a socially mediated process occurring within the zone of proximal development. Within this zone, discourse plays a mediating role in the co-construction of knowledge. Language functions not only as means of expression, but as a cultural tool that shapes thought as well. Dialogic exchanges among peers and with educators—characterised by scaffolding, guided questioning and feedback—facilitate the development of higher-order thinking skills (Mavrikis et al., 2018). Collectively, Sfard's and Vygotsky's theoretical contributions offer a robust foundation for exploring how discourse drives mathematical understanding and provide a compelling rationale for investigating the role of AI in supporting, extending, or emulating these dialogic processes in educational settings (Bringula et al., 2016).

Overview of AI Technologies Relevant to Discourse

A range of AI technologies has emerged with the capacity to enhance discourse-rich mathematics education environments. One of the most prominent is natural language processing (NLP), which enables machines to understand, interpret, and generate human language. In educational contexts, NLP facilitates the automated analysis of student responses, offering insights into the depth of understanding and enabling timely, formative feedback. This supports students in refining their reasoning and communication skills (Spitzer & Moeller, 2023).

Intelligent Tutoring Systems (ITS) represent another significant advancement. These systems integrate rule-based logic and adaptive algorithms to provide individualised learning experiences. They simulate teacher scaffolding by adjusting hints and prompts in real time based on learner input, guiding students through problem-solving tasks, and promoting mathematical dialogue. Additionally, conversational agents and chatbots, powered by LLMs, engage students in real-time discussions that prompt reflection, challenge misconceptions, and deepen conceptual understanding (Charland et al., 2024).

Furthermore, AI-augmented analytics dashboards provide teachers with real-time insights into classroom discourse. These tools identify patterns in student interactions, track conceptual progression, and highlight emerging misunderstandings. Such capabilities allow educators to make data-informed instructional decisions, and foster more equitable participation (Karacı et al., 2018). When integrated effectively, these AI tools do not merely function as technological add-ons but act as reflective instruments for both teaching and learning, amplifying the quality and reach of mathematical discourse (Jiménez et al., 2021).

Linkage Between AI, Discourse and Indicators of SDG 4

AI-powered discourse technologies align closely with the targets of Sustainable Development Goal 4 (SDG 4), which seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. By enabling personalized feedback, adaptive instruction, and formative assessment through dialogic engagement, these technologies significantly contribute to improving learning outcomes (Target 4.1) (Maity & Deroy, 2024). Tailoring mathematical learning experiences to individual needs enhances student achievement and fosters deeper

conceptual development, as emphasized within the theoretical frameworks of Sfard and Vygotsky (Maity & Deroy, 2024; Meylani, 2025d).

Beyond learning outcomes, AI-powered discourse also advances equity and inclusion (Target 4.5) by addressing barriers to participation. Features such as multilingual support, culturally responsive design, and adaptive scaffolding allow these tools to meet the needs of diverse learners, particularly in underserved and linguistically heterogeneous classrooms (Alobaidi et al., 2015; Cao, 2023; Meylani & Kaplan, 2025; Meylani, 2025c). These adaptations ensure that mathematical discourse remains accessible, engaging, and meaningful for all students, thus strengthening inclusive educational practices in line with SDG 4.

AI further supports teacher professional development (Target 4.c) by offering reflective practice tools that analyze classroom discourse and provide evidence-based feedback on questioning strategies and dialogic engagement (Son, 2024; Ok et al., 2025). These feedback mechanisms enable teachers to refine their instructional approaches, assess inclusivity, and adjust practices based on rich dialogic data, contributing to both individual and systemic pedagogical growth.

When anchored in sociocultural theory, AI technologies are not merely technological interventions but serve as mediators of equitable and engaging mathematical experiences (López Chávez et al., 2017). Their capacity to extend high-quality discourse practices at scale reinforces the importance of dialogic engagement in fostering conceptual understanding and educational equity. The integration of Sfard's and Vygotsky's theoretical perspectives with AI technologies strengthens this framework, ensuring that discourse-centered instruction supports the broader realization of SDG 4 targets.

However, the effective use of AI in discourse must remain firmly rooted in ethical and pedagogical commitments derived from sociocultural theories. AI systems must be designed to reinforce collaborative learning processes, respect the cultural-historical contexts of learners, and preserve the human elements essential to education. Without such alignment, AI risks perpetuating exclusionary patterns or displacing critical human interactions. Thus, the theoretical grounding provided by Sfard and Vygotsky offers a critical anchor for evaluating the pedagogical legitimacy and social implications of AI-powered discourse technologies in mathematics education.

Methodology

Review Design

This study adopted a systematic review methodology to synthesise and critically examine empirical and theoretical research on AI-powered discourse in mathematics education. A systematic review is well-suited to this inquiry as it offers a rigorous, transparent, and replicable approach to mapping the current landscape of research; identifying patterns and gaps, and drawing conclusions based on accumulated evidence. Given the interdisciplinary nature of the topic—spanning mathematics education, AI and educational policy—a structured review method ensures the inclusion of diverse perspectives and methodological approaches.

The review process was informed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which provide a standardised protocol for conducting literature reviews. Following this protocol enhances the credibility of the findings and supports the synthesis of complex and heterogeneous

studies. The PRISMA framework guided the formulation of search strategies, inclusion and exclusion criteria, screening procedures, and data extraction processes.

Inclusion and Exclusion Criteria

To ensure relevance and quality, the review carefully applied defined inclusion and exclusion criteria. Studies published between 2010 and 2025 were considered to capture the most contemporary developments in AI technologies and discourse practices. Only peer-reviewed journal articles, empirical studies, theoretical papers, and meta-analyses were included, ensuring academic rigor and credibility.

The focus was restricted to studies that explored AI applications in discourse-rich mathematics learning environments. This included interventions in primary, secondary, and preservice teacher education settings, while excluding early childhood and higher education contexts that were not explicitly focused on mathematics discourse. Studies that addressed AI in education without a clear connection to discourse practices or mathematical content were also excluded. The selected studies were required to engage directly with teaching and learning processes, rather than focusing solely on algorithm development or system design without pedagogical implementation.

Databases and Search Strategy

The literature search was conducted across five major academic databases known for their comprehensive coverage of educational and technological research: ERIC, Scopus, Web of Science, IEEE Xplore, and Education Research Complete. These databases were selected to ensure the inclusion of studies from both education and computer science disciplines.

Search terms were developed iteratively and refined through preliminary searches. The final search string combined keywords related to artificial intelligence, discourse, mathematics education, and sustainable development. The following Boolean expression was used: ("artificial intelligence" OR "AI") AND ("mathematical discourse" OR "mathematics discussion" OR "dialogic teaching") AND ("education") AND ("SDG 4" OR "quality education"). The search was limited to English-language publications and was conducted across titles, abstracts, and keywords to maximise relevance.

Screening and Selection Process

The screening process unfolded in two stages: title and abstract screening, followed by full-text review. In the first stage, all search results were imported into a reference management system and screened for relevance based on titles and abstracts. Duplicates were removed, and studies that met the basic inclusion criteria were retained for full-text examination.

During the second stage, full texts of potentially eligible studies were reviewed in detail to confirm their alignment with the scope of the review. Inter-rater reliability was ensured by involving two reviewers in both stages of the screening process. Discrepancies in selection decisions were resolved through discussion and consensus. In cases of persistent disagreement, a third reviewer was consulted.

Data Extraction and Coding

A structured coding scheme was used to extract key data from each included study. Extracted data included the following variables: author(s), year of publication, country of study, level of education (primary, secondary, preservice), type of AI technology used and its primary functionality. Information on the type and quality of discourse analysed or supported was also recorded.

Additional coding focused on reported outcomes, categorised as cognitive (e.g., reasoning, problem-solving), social (e.g., participation, collaboration), or equitable (e.g., access, inclusion). Studies were also coded for alignment with SDG 4 indicators, such as improvements in learning outcomes, reduction of disparities, and support for teacher development. This coding process enabled thematic synthesis and comparison across diverse studies.

Quality Appraisal

To evaluate the methodological quality of the included studies, established critical appraisal tools were applied. For qualitative studies, the Critical Appraisal Skills Programme (CASP) checklist was used, while mixed methods and quantitative studies were assessed using the Mixed Methods Appraisal Tool (MMAT). Each study received a score based on clarity of research questions, appropriateness of methodology, validity of findings, and relevance to the review topic.

Studies were categorised as high, medium, or low methodological quality. This quality assessment helped contextualise findings and ensured that interpretations were grounded in robust and trustworthy evidence. The appraisal process also highlighted areas where future research could improve methodological rigor and transparency.

Findings

Distribution and Trends in AI-Supported Discourse Research

Table 1 presents a categorisation of scholarly citations under four thematic areas related to the integration of artificial intelligence (AI) in mathematics education discourse.

A total of 25 citations are distributed across these categories, offering a structured lens into where current research efforts are concentrated and what gaps remain.

Distribution Across Categories

- Types of AI applications used to support discourse and impact on discourse practices in Mathematics each include 6 citations (24% of total references per category). This balance suggests that the literature equally emphasises both the technical implementation of AI tools (e.g., NLP, ITS, chatbots, dashboards) and their pedagogical impacts (e.g., participation, reasoning, metacognition).
- Reported challenges and limitations were drawn from 7 citations (28%), the highest among all categories. This reflects a growing scholarly concern with the ethical, technical and infrastructural barriers to effective AI integration.
- Contributions to SDG 4 are represented by only 6 citations (24%), indicating that while alignment with global education goals is acknowledged, it remains an underexplored area in AI discourse literature.

This distribution highlights a tendency in the field to focus heavily on the affordances and challenges of AI, with relatively fewer studies explicitly linking these innovations to broader equity and sustainability goals.

Table 1

Categorisation of Citations by Thematic Focus and Frequency in AI-Supported Discourse in Mathematics Education

Themes	Citations	Number of Citations
Types of AI Applications Used to Support Discourse	Zhang and Zhang (2024); Kim et al. (2021); Ramasamy and Zainal (2023); Saimon et al. (2024); Wang et al. (2025); Ferrans (2023)	6
Impact on Discourse Practices in Mathematics	Saimon et al. (2024); Mier and Blanco (2022); LaRusso et al. (2024); Purwandari (2021); Rees (2019); Dan et al. (2023)	6
Contributions to SDG 4	Al-Smadi (2017); Nugroho et al. (2020); Cao (2023); Sharifuddin and Hashim (2024); Meylani (2025a); Meylani et al. (2025)	4
Reported Challenges and Limitations	Rees and Roth (2019); Al-Buraiki (2024); Na (2023); Xatamova and Ashurov (2024); Jiang et al. (2018); Song and Cheng (2022); Toscano et al. (2019)	7

Geographical Distribution of the Literature

An analysis of the affiliations and study contexts in the cited works reveals a strong representation from East and Southeast Asia, North America, and the Middle East, with limited contributions from Sub-Saharan Africa and Latin America:

- ***East and Southeast Asia****:* Studies by Saimon et al. (2024) Na (2023) and Kim et al. (2021) are based in South Korea, Malaysia and China, respectively, reflecting robust regional interest in adaptive AI systems in mathematics instruction.
- ***North America:*** Contributions of scholars such as LaRusso et al., (2024), Ferrans (2023) and Rees and Roth (2019) demonstrate the integration of AI dashboards and discourse analytics in U.S.-based classrooms.
- ***Middle East:*** Research by Al-Smadi (2017) and Al-Buraiki (2024) represents efforts in Jordan and Oman, focusing on AI's impact on achievement and speech recognition limitations.
- ***Limited African representation:*** While African contexts are indirectly addressed in global reviews, the lack of region-specific citations underscores a critical research gap in under-resourced settings.
- ***Latin America and Central Asia:*** This area is also underrepresented, suggesting the need for broader inclusion of Global South perspectives in studies on AI-mediated discourse and SDG 4 alignment.

Implications

The findings suggest that while there is robust evidence supporting the potential of AI to transform mathematics discourse, research remains geographically uneven and thematically skewed toward implementation and challenges. There is a pressing need for:

- Expanded research into SDG 4 indicators, especially those related to equity and lifelong learning - in diverse and marginalised educational contexts.
- Greater investment in cross-regional studies to understand the sociocultural dynamics of AI discourse applications.
- Ethical frameworks and capacity-building strategies that respond to the technical, pedagogical and privacy concerns raised, particularly in multilingual and low-resource settings.

Results

Types of AI Applications Used to Support Discourse

A growing body of literature identifies a wide range ofAI applications specifically designed to enhance discourse in mathematics education. One of the most prominent categories is NLP tools, which are increasingly embedded in digital learning environments to analyse the structure, content and quality of student responses. These tools support automated feedback generation, facilitate the identification of misconceptions, and classify patterns of mathematical argumentation (Zhang & Zhang, 2024). When integrated into ITS, NLP enables the dynamic tracking of student reasoning, allowing systems to deliver tailored scaffolding aligned with individual learning trajectories (Kim et al., 2021). This integration underscores the potential of AI to foster personalised and discourse-rich mathematics learning.

Conversational agents and chatbots represent another critical subset of AI applications. These systems simulate dialogic exchanges by offering prompts, corrective feedback and follow-up questions that guide students through mathematical reasoning processes. Advanced agents can sustain multi-turn dialogues that approximate the depth and responsiveness of expert human instruction (Ramasamy & Zainal, 2023). Research indicates that such agents promote exploratory talk, enhance reasoning, and support metacognitive development, contributing to more reflective and meaningful learning experiences (Saimon et al., 2024). In parallel, AI-driven analytics dashboards—powered by machine learning—aggregate data from classroom discourse, including voice and text inputs, and visualise indicators such as engagement levels, participation rates and conceptual depth (Wang et al., 2025). These tools empower teachers with actionable insights for real-time instructional adaptation and early intervention for struggling learners (Ferrans, 2023).

Impact on Discourse Practices in Mathematics

The integration of AI tools in mathematics classrooms has brought about meaningful shifts in discourse practices. A consistent finding across empirical studies is a marked increase in student participation, particularly among learners who are typically hesitant to contribute in whole-class discussions. AI systems provide a low-stakes environment that encourages trial and error, thereby lowering the affective barriers associated with verbal expression (Saimon et al., 2024; Mier & Blanco, 2022). In addition to expanding participation, these technologies have been shown to enhance

the complexity and depth of student reasoning. AI tools that prompt learners to explain their thinking or justify their responses often lead to more elaborate contributions, fostering dialogic interactions and deeper mathematical understanding (LaRusso et al., 2024; Purwandari, 2021).

Students engaged in AI-mediated discourse environments display increased usage of mathematical language, improved argumentation skills, and heightened capacity for reflective thinking (Rees, 2019). The feedback loops provided by AI systems are instrumental in cultivating metacognitive awareness, enabling students to monitor, evaluate, and refine their own thinking processes. These interactions nurture both cognitive and social dimensions of learning, creating opportunities for meaningful engagement with mathematical ideas and supporting the development of autonomous, self-regulated learners (Dan et al., 2023).

Contributions to SDG 4

The reviewed research provides strong evidence that AI-supported discourse practices are well-aligned with the objectives of Sustainable Development Goal 4 (SDG 4). Studies suggest that when implemented ethically and inclusively, AI contributes significantly to SDG 4 targets by personalizing instruction and supporting reflective professional practices among teachers (Meylani, 2025a; Meylani et al., 2025).

Specifically, these technologies contribute to **Target 4.1**—improving learning outcomes—by advancing conceptual understanding, strengthening problem-solving abilities, and boosting academic performance (Nugroho et al., 2020; Al-Smadi, 2017). Such benefits are particularly evident in classrooms where conventional teaching methods have historically constrained opportunities for rich dialogue and feedback.

AI applications also promote equity and inclusion in line with **Target 4.5** by offering adaptive support tailored to the needs of learners from linguistically, socioeconomically and academically diverse backgrounds. Features such as multilingual interfaces and culturally responsive content ensure that students access discourse-rich mathematics education regardless of their context (Cao, 2023). Moreover, the use of AI for professional development supports **Target 4.c**, equipping teachers with tools for reflective practice. Analytics dashboards and automated feedback mechanisms help educators assess their discourse strategies, identify student engagement trends and make data-informed pedagogical decisions (Sharifuddin & Hashim, 2024).

Reported Challenges and Limitations

Despite these promising developments, several challenges and limitations persist regarding the implementation of AI to support discourse in mathematics education. A frequently cited issue is the technological limitation of AI systems, particularly their difficulties with accurate speech recognition in noisy or multilingual classroom settings (Al-Buraiki, 2024; Rees & Roth, 2019). Additionally, current AI tools often struggle to interpret nuanced, context-specific student responses, limiting their effectiveness in supporting complex discourse without human oversight (Na, 2023).

Ethical considerations also guarantee serious attention. The collection and processing of student discourse data raise significant concerns related to privacy, informed consent, and algorithmic bias—especially in educational systems that lack comprehensive data protection policies (Xatamova & Ashurov, 2024; Jiang et al., 2018).

Another critical limitation concerns teacher preparedness and implementation fidelity. Effective use of AI tools often requires extensive professional development, yet many educators report difficulties in aligning AI-generated insights with their instructional goals or interpreting system feedback in pedagogically meaningful ways (Song & Cheng, 2022; Toscano et al., 2019). Addressing these challenges calls for robust capacity-building efforts and collaborative design processes that actively involve educators in the creation and refinement of AI systems.

Interpretation of Findings

Recent research highlights the transformative impact of AI on discourse practices in mathematics education. Applications such as ITS, and analytics dashboards are enhancing student reasoning, engagement and metacognition across diverse learning environments (Wang et al., 2025; Zhang & Zhang, 2024; Ramasamy & Zainal, 2023; Kim et al., 2021).

NLP tools embedded in ITS dynamically analyse student responses to identify misconceptions, assess reasoning quality, and deliver tailored scaffolding, supporting discourse-rich and personalised learning (Zhang & Zhang, 2024; Kim et al., 2021). Conversational agents simulate dialogic exchanges, offering prompts and feedback that encourage reflective reasoning and exploratory talk (Saimon et al., 2024; Ramasamy & Zainal, 2023;). Simultaneously, AI-driven dashboards visualise real-time discourse data, allowing teachers to adapt instruction and identify students in need of support (Wang et al., 2025; Ferrans, 2023).

AI applications have increased student participation, particularly among those hesitant to engage in traditional discussions. By lowering social risks, these tools foster detailed responses and deeper conceptual engagement (LaRusso et al., 2024; Saimon et al., 2024; Mier & Blanco, 2022). Students also exhibit improved use of mathematical language, argumentation, and self-regulation (Dan et al., 2023; Rees, 2019), demonstrating AI's potential to support both cognitive and social aspects of discourse.

In alignment with SDG 4, AI enhances learning outcomes (Target 4.1) and supports equity (Target 4.5) by offering multilingual, adaptive and culturally responsive tools (Cao, 2023; Nugroho et al., 2020; Al-Smadi, 2017). These systems also contribute to teacher development (Target 4.c) by enabling reflective practice through automated discourse analytics (Sharifuddin & Hashim, 2024).

However, limitations remain. AI tools often struggle with speech recognition accuracy in noisy or multilingual settings and lack the nuance to interpret complex student responses without human oversight (Al-Buraiki, 2024; Na, 2023; Rees & Roth, 2019). Ethical concerns related to data privacy, consent and algorithmic bias are also significant, especially in underregulated contexts (Xatamova & Ashurov, 2024; Jiang et al., 2018). Moreover, successful integration requires sustained teacher training, as many educators face challenges interpreting AI-generated insights (Song & Cheng, 2022; Toscano et al., 2019).

To fully realise the benefits of AI in mathematics discourse, future efforts must address these technical, ethical and pedagogical challenges through inclusive design and comprehensive professional development.

Implications for Classroom Practice, Teacher Education, and Policy

Findings from this review suggest that AI technologies should be seen as amplifiers of human instruction, not replacements. Classroom practices must prioritize teacher–AI partnerships in which educators use AI feedback not mechanistically, but interpretively—considering context, student backgrounds, and curriculum goals (Jiménez et al., 2021; Son, 2024). Teacher education programs must incorporate critical AI literacy, enabling future educators to understand the affordances and limitations of discourse analytics, automated scaffolding, and chatbot integration (Karabacak & Bilgin, 2025; Meylani, 2025d).

Professional development should also focus on cultivating data interpretation skills, encouraging educators to reflect on the social and cultural dimensions of classroom talk. AI dashboards, for example, should serve as starting points for instructional inquiry, not endpoints for judgment. Equally, teachers should be equipped to advocate for ethical use of student discourse data, especially in contexts where privacy laws or institutional oversight may be lacking (Rees & Roth, 2019; Sharifuddin & Hashim, 2024).

At the policy level, governments and education ministries must address infrastructure gaps that limit the adoption of AI-enhanced learning environments in under-resourced regions. Investment in inclusive design, open-source platforms, and multilingual technologies will help ensure broader access and sustainability (Alexander et al., 2024; Meylani et al., 2025). AI integration should be governed by pedagogical—not commercial—priorities, ensuring that tools align with curricular goals and human-centered learning principles.

Research Gaps and Future Directions

Despite the encouraging evidence, the review also points to significant gaps in the current literature. Firstly, there is a lack of longitudinal research exploring how sustained exposure to AI-supported discourse environments influences learning trajectories, classroom culture and student identity in mathematics. Future studies should examine not just short-term outcomes, but long-term changes in students' mathematical reasoning and communication skills.

Secondly, there is a need for more rigorous experimental designs, including randomised controlled trials, to establish causal links between AI use and specific discourse-related outcomes. Many of the reviewed studies employed exploratory or descriptive methods, which, while informative, limit generalisability. Methodologically robust studies would be essential for building a more conclusive evidence base.

Thirdly, the role of multimodal discourse—encompassing gestures, visual representations and digital artifacts remains underexplored in AI research. Emerging technologies such as computer vision and speech-gesture integration could enable the capture and analysis of richer forms of classroom interaction. Investigating how AI supports these multimodal dimensions of discourse would broaden the understanding of its pedagogical potential.

Lastly, localised research in Global South contexts remains sparse. Most of the studies reviewed originated from technologically advanced regions, raising concerns about geographic and cultural bias. Future research should prioritise context-specific investigations that account for diverse linguistic, technological and socio-economic

conditions. This will ensure that the development and application of AI in mathematics education is both globally informed and locally relevant.

Conclusion

This systematic review examined contemporary research on the role of Ai in supporting mathematical discourse within educational settings, with a specific focus on how such interventions contribute to the objectives of SDG 4. The findings reveal that AI-powered tools—including NLP systems, conversational agents and intelligent dashboards can significantly enhance the quality and inclusivity of discourse in mathematics classrooms. These technologies facilitate more equitable participation, promote deeper reasoning, and provide real-time, individualised feedback that supports both learners and teachers.

The review highlights the transformative potential of AI in advancing quality education by aligning technological innovations with dialogic pedagogies and sociocultural principles of learning. AI-powered discourse interventions support several key SDG 4 targets: they contribute to improved learning outcomes (Target 4.1); foster inclusive participation among marginalised groups (Target 4.5); and strengthen teacher capacity through professional feedback mechanisms (Target 4.c). When designed and implemented thoughtfully, these technologies serve as tools for equity and excellence, helping to close opportunity gaps in mathematics education.

Strategic Recommendations to Harness AI for Advancing SDG 4

Strategic recommendations emerging from this review include the need for inclusive AI design, teacher-centred implementation models, and supportive policy infrastructures. Schools and education systems should prioritise professional development that empowers teachers to interpret AI-generated insights and integrate them meaningfully into instruction. Policymakers should ensure equitable access to AI tools and address infrastructure gaps in underserved regions. Developers should engage educators in the design process to ensure that AI systems reflect pedagogical best practices and cultural responsiveness.

In light of the critical role that discourse plays in fostering mathematical understanding, AI interventions should be evaluated not only for efficiency or scalability, but for their alignment with human-centred learning principles. AI systems should be leveraged to support formative assessment, facilitate collaborative inquiry, and extend dialogic practices—particularly in contexts where traditional instruction limits student voice or agency.

Limitations of the Review

Despite its comprehensive scope, this review is not without limitations. The analysis was bound by the selection of five academic databases, which, while extensive, may have excluded relevant studies published in grey literature, conference proceedings or emerging regional journals. The review was also limited to English-language publications, introducing a potential language bias that may have excluded important contributions from non-English-speaking regions.

Furthermore, the rapidly evolving nature of AI technologies presents challenges in establishing a consistent taxonomy for comparing applications. The diversity of study designs, contexts and definitions of discourse and AI across literature made synthesis

complex. While this diversity enriches the field, it also limits the ability to generalise findings across educational systems and learner populations.

Contribution to the Field

Despite these limitations, this review makes a meaningful contribution to the fields of educational technology and mathematics education by offering a synthesised understanding of how AI supports discourse and aligns with global educational goals. It underscores the importance of viewing AI not as a neutral or isolated innovation, but as a socially embedded tool that must be guided by ethical, pedagogical, and equity-driven considerations. As AI continues to shape the future of education, harnessing its potential for meaningful mathematical discourse would be essential in realising the transformative vision of SDG 4.

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