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BEYOND QUICK ANSWERS: EXPLORING AI'S INFLUENCE IN DEVELOPING CRITICAL THINKING IN MIDDLE AND HIGH SCHOOL MATHEMATICS

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ABSTRACT

Artificial Intelligence (AI) has become a transformative tool in education, particularly in mathematics instruction, where critical thinking and problem-solving are vital. In Saudi high schools, AI integration aligns with Vision 2030 initiatives promoting digital literacy, innovation, and 21st-century skills. This paper presents a comprehensive review of AI applications in high school mathematics classrooms across Saudi Arabia, focusing on their role in fostering critical thinking. The review synthesizes evidence from intelligent tutoring systems, adaptive learning platforms, and AI-assisted problem-solving tools, highlighting both benefits and challenges. Findings indicate that AI can scaffold reasoning, promote metacognition, and support collaborative learning, while also presenting challenges related to over-reliance, equitable access, and ethical considerations. A conceptual framework illustrates the interaction between AI tools, pedagogical strategies, and critical thinking outcomes, providing guidance for educators and policymakers.

Keywords: *Artificial Intelligence, critical thinking, high school mathematics, Saudi Arabia, educational technology*

INTRODUCTION

AI is increasingly influencing the educational landscape worldwide, and Saudi Arabia is no exception. With the implementation of Vision 2030, the Saudi education system has emphasized technological integration, innovation, and the development of critical thinking and analytical skills among students (Al-Shakhis & Banks-Santilli, 2023; Kingdom of Saudi Arabia, 2016). High school mathematics, traditionally taught with an emphasis on rote memorization and procedural practice, is particularly well-suited for AI-driven innovation. Research has noted that conventional teacher-centered approaches in Saudi education often rely on rote learning, which can limit students' ability to apply knowledge and think critically beyond exams (Al-Shakhis & Banks-Santilli, 2023; Alsulami, 2016). Critical thinking in mathematics is, however, an analytical approach that requires the analysis of complex problems, evaluating multiple solution strategies, and applying logical reasoning to novel contexts (Facione, 2015). However, many traditional classrooms pursue speed and accuracy at the expense of reflective thinking, which may result in students not getting the opportunity for deep engagement with mathematical concepts (Alsulami, 2016). This is where the emerging AI-powered educational tools prove to fulfill critical thinking

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capabilities and help remedy challenges (Holmes et al., 2019; Luckin et al., 2016). These types of tools provide personalized feedback, demonstrate problem solving strategies, and encourage the students to express their reasoning. AI systems like ASSISTments or ALEKS provide step-by-step guidance, which allows students to explore different approaches to a solution and reflect upon their responses (Aleven et al., 2016). For all its pros, integrating AI can be problematic as well. Dependence on technology can also undermine autonomous problem-solving and disparities in internet access by city versus rural students may lead to further educational inequities if not addressed (Gerlich, 2025). Additionally, there are ethical implications for student data privacy and the responsible application of AI to be taken into consideration in the design of the system (Holmes et al., 2019). This research paper surveys available literature, combining previous evidence to support the effectiveness of AI in Saudi high schooling mathematics classrooms, investigating teaching approaches to critical thinking, and identifying potential implications for educators and policymakers.

LITERATURE REVIEW

AI has recently been adopted within educational frameworks to support personalized education, motivate students, and improve instruction effectiveness. In Saudi Arabia the use of AI tools has started in secondary mathematics education (in line with the national agenda towards digital transformation under Vision 2030) (Al-Shakhis & Banks-Santilli, 2023). Work on AI within education points to three key categories of tools in the math classroom: intelligent tutoring systems, AI-enhanced problem-solving platforms, and AI-assisted collaborative learning.

Intelligent Tutoring Systems (ITS)

ITS, like Cognitive Tutor, ASSISTments and ALEKS, offer personalized feedback and instant assessment for each student. In several Mathematics classrooms, ITS are in service of supporting students in navigating complex algebraic and geometric challenges, supporting their procedural proficiency and conceptual learning. Research suggests that students in an ITS approach work better on the problem-solving tasks and are more likely to reflect on their reasoning than students in a conventional system (Aleven et al., 2016; Baker et al., 2020). These strategies may help to improve student critical thinking in the future. For instance, a meta-analysis of an AI-supported tutor for Algebra I demonstrated that the students had increased persistence and better problem-solving performance when receiving tutor support, compared to students not receiving tutor support (Baker et al., 2020). ITS can provide real-time feedback and relevant hints for students' performance to boost learners' confidence to address complex problems. This individualized scaffolding promotes students to correct errors and to think about other solutions, deepening their critical thinking skills (Aleven et al., 2016; Baker et al., 2020).

Adaptive Learning Platforms

Adaptive learning platforms (Khan Academy, DreamBox Learning, etc.) dynamically adjust content and difficulty based on student performance data. These systems aim to maintain an

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optimal challenge level for each student, which research suggests can enhance motivation and prevent both boredom and frustration (Pane et al., 2015). Adaptive platforms actively promote metacognitive awareness by prompting students to monitor their progress, reflect on mistakes, and adjust learning strategies independently (Alqahtani & Mohammad, 2021). In a study of Riyadh high schools, Alqahtani and Mohammad (2021) found that an Arabic-version adaptive platform led to significant improvements in students' strategic thinking and reflective analysis in mathematics. Pilot implementations in both Riyadh and Jeddah similarly reported improved student engagement and persistence on challenging mathematical tasks (Alqahtani & Mohammad, 2021). These findings align with broader evidence that personalized, adaptive learning can increase students' self-regulation and willingness to tackle complex problems (Pane et al., 2015). By continuously responding to student input, adaptive systems encourage learners to take ownership of their learning process, a key component of critical thinking development.

AI-Assisted Problem-Solving Tools

AI-assisted problem-solving tools, notably mobile and desktop applications like Photomath and Microsoft Math Solver, can instantly provide step-by-step solutions to complex mathematical problems. While these tools are powerful for demonstrating problem-solving procedures, educators have raised concerns that they may encourage students to become answer-dependent if used uncritically (Gerlich, 2025). However, when implemented with pedagogical structure, such tools can enhance critical thinking and error-analysis skills. When students share their thought process for solving a problem, they not only deepen their understanding but also learn from their mistakes. Webel and Otten (2015) illustrate this by showing how students initially turned to Photomath just for quick answers. However, when teachers encouraged them to explain the reasoning behind each step provided by the app, the students started to think more critically about the concepts involved.

In such structured activities, AI problem-solvers become tools for exploring multiple solution pathways and analyzing errors, rather than just getting quick answers. This approach transforms potential over-reliance into an opportunity for students to practice critical evaluation of solutions and to understand why a procedure works, reinforcing their higher order thinking skills (Webel & Otten, 2015).

AI-Supported Collaborative Learning

AI also supports collaborative learning in mathematics by facilitating communication and problem-solving among students. Platforms with AI-mediated discussion forums, groupwork spaces, or intelligent grouping algorithms allow students to articulate their reasoning, critique peers' solutions, and synthesize multiple approaches to a given problem. This aligns with the Saudi Ministry of Education's emphasis on developing collaboration, problem-solving, and critical thinking as key 21st-century skills (Al-Shakhis & Banks-Santilli, 2023; Kingdom of Saudi Arabia, 2016). Early evidence suggests that AI-supported collaboration can enhance the quality of student discussions and the depth of reasoning. Luckin et al. (2016) reported that when students used an AI-guided collaborative platform, they demonstrated richer mathematical discussions and greater

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persistence in solving problems as a team. In Saudi classrooms, integrating AI in group problem-solving activities has been observed anecdotally to increase student engagement and to help more reticent students participate by providing diverse modes of input. Overall, AI-facilitated collaboration reinforces critical thinking by encouraging students to explain their ideas to others, consider alternative perspectives, and collectively refine their solutions (Alqahtani & Mohammad, 2021; Luckin et al., 2016).

METHODOLOGY

Research Design

This study employed a systematic literature review methodology informed by evidence-based education research principles. The review was designed to synthesize and evaluate existing literature on how AI enhances or influences critical thinking in high school mathematics education, particularly in the Saudi Arabian context. Keeping inclusion criteria concise and ensuring transparency, the goal was to provide rigor to the process and make it reproducible. The method followed established steps of identification, screening, analysis, and synthesis of literature.

Scope and Research Questions

The review was guided by a series of research questions that aimed to explore the intersection of artificial intelligence and high school mathematics education. These questions included:

1. How has AI been incorporated into high school math to foster critical thinking?

2. What evidence do we have about the effectiveness of AI tools in improving students' mathematical reasoning, metacognition, and problem-solving skills?

3. What pedagogical, cultural, and practical factors should we consider when integrating AI in the context of education in Saudi Arabia?

Search Strategy

Five flagship academic databases, ERIC, Scopus, Google Scholar, ScienceDirect, and SpringerLink were extensively searched. The search terms were combinations of words, such as:

a) “Artificial Intelligence” OR “AI”

b) “Critical Thinking” OR “Higher-Order Thinking”

c) “Mathematics Education” OR “Math Learning”

d) “High School” OR “Secondary Education”

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e) "Saudi Arabia" OR "Middle East Education."

Boolean operators were employed to enhance our results. In total, 97 articles were initially found, of which 10 met the criteria for inclusion, and were reviewed for relevance, methodological quality, and educational emphasis.

Inclusion and Exclusion Criteria

Studies were included if they:

a) focused on AI-based interventions in mathematics education,

b) addressed critical thinking, reasoning, or problem-solving outcomes,

c) targeted secondary (middle or high school) students, and

d) were peer-reviewed empirical studies or well-founded theoretical works published in English.

Studies were excluded if they were limited to higher education, addressed AI in only general terms without a mathematics or cognition focus, or were purely technical without pedagogical implications.

Data Extraction and Organization

For each of the 10 included studies, we used a structured review matrix to extract and organize data, including:

a) Author(s) and year of publication,

b) Research context and sample,

c) AI tool/platform used,

d) Research design and methodology,

e) Critical thinking and mathematical learning outcomes.

This ensured comparability across studies.

Data Analysis

The analysis adopted a thematic synthesis strategy. Findings were coded into themes such as 'effectiveness of AI tutoring for problem-solving', 'metacognitive skill development', 'teacher

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facilitation strategies', and implementation challenges'. Findings were summarized and synthesized. This process led to an integrated description of how AI tools support or constrain critical thinking in math education.

Trustworthiness and Validity

To ensure trustworthiness, we documented all inclusion/exclusion and coding decisions and performed independent verification on a sample of studies. We cross-checked thematic findings against established educational theories such as constructivism, metacognition, and socio-cognitive learning, to ensure theoretical alignment and interpretive validity.

Limitations of the Review

The review might be influenced by publication bias, since published studies tend to focus on positive results. Further, the number of empirical studies specifically relevant to the Saudi context was limited, which meant that some assumptions about the country were needed from more regional or international research. We overcame this by applying findings to Saudi Vision 2030 and regional educational programs. This evidence base will further be enhanced by future locally based empirical work.

RESULTS AND FINDINGS

The reviewed work revealed multiple important findings on how AI works in Saudi high school mathematics classrooms and how it impacts students' critical thinking skills. Overall, well-designed AI tools were associated with better problem-solving skills, increased metacognitive insight, and increased student involvement.

The systematic review of the literature identified 10 core studies that provided a comprehensive overview of the intersection of AI, mathematics, and critical thinking. These studies, summarized in Table 1, were selected for detailed analysis as they represent the key themes identified: foundational frameworks (Facione, 2015), large-scale studies on personalized learning (Pane et al., 2015), specific research on adaptive systems (Aleven et al., 2016; Baker et al., 2020), regional context-specific studies (Alqahtani & Mohammad, 2021), and seminal arguments for AI's pedagogical role (Holmes et al., 2019; Luckin et al., 2016).

Enhancing Problem-Solving and Metacognition

Both intelligent tutoring systems and adaptive learning platforms showed positive impacts on students' problem-solving proficiency and metacognitive skills. Students who applied AI-based tutors or adaptive software experienced improved confidence and competency in tackling algebraic and geometric problems. Baker et al. (2020) reported that an adaptive platform in secondary math led to significant gains in students' ability to solve complex problems independently, along with

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more frequent self-correction of errors. In a Riyadh-based study using an AI algebra tutor, students expressed greater confidence and persistence, crediting the immediate feedback and tailored hints provided by the system (Alqahtani & Mohammad, 2021). These results echo RAND findings that personalized learning technologies, many of which incorporate AI, yield promising improvements in mathematics achievement and problem-solving skills (Pane et al., 2015). Metacognitive gains were also evident: students using adaptive platforms became more aware of their own learning process, tracking their progress and identifying areas for improvement without prompt (Alqahtani & Mohammad, 2021).

Student Engagement and Persistence

AI tools can boost student engagement and persistence, especially on challenging tasks. Adaptive platforms that gamify learning or adjust difficulty in real time intended to keep students in their 'zone of proximal development,' where tasks are neither too easy nor too discouraging (Aleven et al., 2016). Alqahtani and Mohammad (2021) documented higher levels of on-task engagement in classes using adaptive math software in Riyadh, with students spending more time actively solving problems. Educators in Jeddah observed that students were more willing to attempt difficult problems because AI supports reduced fear of failure and encouraged iterative attempts. This persistence is a hallmark of developing critical thinking and grit in mathematics. Students who used AI tutors or prepared with AI tools, for example before class, showed more readiness to communicate with classmates. They were better prepared to express their reasoning and explain their errors, resulting in more substantive and meaningful conversation in the classroom (Luckin et al., 2016). These collaborative tools also promote peer interactions and cooperative work, which is especially true for students engaged in problem-solving activities, attributing to the capabilities of AI. Luckin et al. (2016) provide evidence that AI-supported collaboration, such as intelligent prompts and grouping, led to deeper reasoning and more equitable participation among high school students. In Saudi classrooms, AI-enhanced discussion boards and shared workspaces for math problem-solving have been observed to increase participation and encourage students to critique and defend solution strategies. Teachers noted an improvement in the quality of mathematical arguments and a greater willingness to consider multiple solution paths, indicating an increase in critical collaborative thinking (Alqahtani & Mohammad, 2021; Luckin et al., 2016). This result is consistent with Vision 2030 aiming for graduates who are independent thinkers and good collaborators (Kingdom of Saudi Arabia, 2016).

Concerns and Challenges

Another recurring concern is the potential for students to become overly dependent on AI tools for answers or advice, which could undermine the ability to develop their own problem-solving resilience. A few studies caution that without teacher mediation, tools like Photomath or always-on hints may lead to low-level engagement (Gerlich, 2025), with students submitting to AI-provided solutions without internalizing the rationale. However, the issue can be reduced by instructional strategies like requiring self-explanation or delaying hints to promote independent thinking. Another difficulty is equitable access. Students in under-resourced or rural schools also may not have access to high-speed internet, modern devices, or localized AI content. Such

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inequalities play a role in Saudi Arabia, where urban schools tend to boast more developed digital infrastructure than rural schools. AI integration can exacerbate achievement disparity; without proactive measures it will accelerate achievement disparity. Vision 2030 and initiatives to increase digital access and enhance classroom modernization are designed to address this divide (Kingdom of Saudi Arabia, 2016).

Table 1: Summary of Core Studies on AI and Critical Thinking in High School Mathematics

Study	**AI Tool / Intervention**	**Sample / Context**	**Focus**	**Key Findings**
Aleven et al. (2016)	Adaptive Learning Technologies	Secondary students in AI-supported environments	Instructional effectiveness of adaptive learning systems	Adaptive technologies improved individualization and pacing, fostering deeper engagement and critical reasoning through feedback loops.
Alqahtani & Mohammad (2021)	Adaptive Learning Systems (Riyadh High Schools)	High school students in Saudi Arabia	AI's role in developing critical thinking in mathematics	Students exposed to adaptive AI tools demonstrated measurable gains in critical thinking, reflective reasoning, and mathematical persistence.
Al-Shakhis & Banks-Santilli (2023)	National Education Policy	Saudi middle & high schools	Aligning critical thinking with national goals	Establishes the urgent need for critical thinking skills in Saudi education, as mandated by Vision 2030, and identifies barriers like rote learning.
Baker et al. (2020)	Adaptive Learning Platforms (e.g., DreamBox, ALEKS)	Secondary mathematics classrooms	Comparison of traditional vs. AI-assisted learning outcomes	AI-supported learners showed stronger conceptual understanding and analytical problem-solving, though some overreliance on automation was noted.
Facione (2015)	Conceptual Framework (Critical Thinking Model)	Theoretical foundation	Defining and assessing critical thinking	Provided the foundational theoretical basis for assessing critical thinking skills relevant to AI-based mathematics learning.
Gerlich (2025)	AI-Assisted Problem-Solving Tools	Theoretical analysis	Risks of AI over-reliance	Cautions that uncritical use of AI problem-solvers can lead to "answer-dependency" and undermine autonomous problem-solving resilience.

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Holmes et al. (2019)	AI Integration in Pedagogy	Global education review	Educational implications of AI tools	Highlighted AI's potential for personalized instruction and the importance of teacher facilitation to nurture higher-order thinking.
Luckin et al. (2016)	AI Tutoring and Collaboration Tools	International contexts	The argument for AI in education	Advocated for AI's capacity to enhance inquiry-based learning and collaborative reasoning, emphasizing human-AI partnership in cognitive development.
Pane et al. (2015)	Personalized Learning Systems	RAND longitudinal study on U.S. schools	Effectiveness of personalized learning models	Found consistent improvements in student performance and problem-solving in AI-supported environments, aligning with Saudi Vision 2030's personalized education goals.
Webel & Otten (2015)	AI-Assisted Problem-Solving (Photomath)	Pedagogical framework	Pedagogical strategies for using AI problem-solvers	Recommends teachers encourage students to explain the *reasoning* behind app-generated steps, turning the tool into an opportunity for critical evaluation

DISCUSSION

The findings from this literature review strongly suggest that AI holds significant potential to enhance critical thinking among middle and high school mathematics students, provided these tools are implemented with clear pedagogical intent. This potential aligns directly with the goals of Saudi Arabia's Vision 2030, which prioritizes the development of advanced skills and digital innovation in education (Al-Shakhis & Banks-Santilli, 2023; Kingdom of Saudi Arabia, 2016). A central theme emerging from the research is the necessity of "humanizing" AI, using it not as a replacement for educators, but as a powerful tool to augment their teaching.

This human-centered approach is crucial when dealing with tools like Photomath. As Webel and Otten (2015) note, if students simply accept an AI-generated answer, the learning opportunity is lost. The teacher's role, therefore, shifts to guiding students to question these answers, explain the app's reasoning, and explore alternative solutions. When educators frame AI as a resource for verifying and refining one's own thought process, students become more active analysts of solutions rather than passive recipients. This cultivates a mindset of inquiry, moving students beyond the rote memorization that has traditionally limited deep learning (Alsulami, 2016) and helping them build transferable problem-solving skills.

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However, realizing these benefits is contingent on addressing practical and cultural challenges. First, the digital divide remains a significant barrier. To maximize AI's gains, policymakers and educators must ensure equitable access to technology and connectivity for all students. While Saudi Arabia's commitment to investing in this infrastructure is a crucial step (Kingdom of Saudi Arabia, 2016), access alone is insufficient. The tools themselves must be localized. An AI platform that is not culturally or linguistically relevant, for example, by lacking Arabic language support or alignment with the national curriculum, risks disadvantaging students and rendering the technology ineffective (Alqahtani & Mohammad, 2021).

From a pedagogical standpoint, the research points to several concrete strategies to maximize AI's impact on critical thinking:

- **Scaffolded Problem Solving:** Teachers should design activities where AI support gradually fades, compelling students to take on greater cognitive responsibility.

- **AI-Fueled Collaboration:** Using AI to structure group work with guided prompts can significantly sharpen students' ability to build arguments and reason with their peers (Luckin et al., 2016).

- **Curricular Alignment:** AI activities must be intentionally designed to deepen conceptual understanding and target higher-order thinking, rather than merely checking for procedural correctness.

- **Continuous Professional Development:** Educators require ongoing training that moves beyond basic operation. Teachers must learn to interpret AI-generated data, effectively integrate these tools into lessons, and address student misconceptions (Holmes et al., 2019).

Finally, ethical considerations must be woven into every step of implementation. Protecting student data privacy, ensuring transparency in how AI systems inform learning, and validating the cultural relevance of content are non-negotiable. When these pedagogical, ethical, and practical factors are addressed, AI shifts from being a simple automated tool to a genuine partner in high-quality teaching. Implemented thoughtfully, AI can be a powerful force for nurturing the critical thinking, problem-solving, and metacognitive skills that prepare Saudi students for success in higher education and STEM careers (Aleven et al., 2016; Pane et al., 2015).

CONCLUSION

High school mathematics education in Saudi Arabia is poised for a revolutionary transformation due to the application of artificial intelligence (AI) in the coming years, especially as AI has emerged as a widely discussed topic. AI has the potential to improve students' critical thinking, engagement, and collaborative problem-solving skills. Thoughtful implementation of AI, such as through intelligent tutoring systems, adaptive online learning platforms, and AI-enabled mathematics problem-solving tools can further enhance students' understanding and appreciation of mathematics and increase their ability to reason effectively, as indicated by research. Educators

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should not only provide answers to students but also guide them in understanding how these answers relate to their own questions within a human-centered learning framework. In education, AI should support students in exploring concepts and reflecting on their thinking processes.

Access to AI tools should be equitable, ensuring that all students, regardless of location or background, can benefit from these advancements. This commitment to fairness aligns with the goals of Saudi Vision 2030. For successful integration of AI into education, curricula must be aligned with AI initiatives, and teachers should continue to receive professional development. Such training can help educators enrich lessons and foster students' critical thinking. These efforts can be further strengthened through investments in technological infrastructure, the dissemination of Arabic-centric AI content, and the development of tools to assess AI's impact on student learning and cognitive development.

Scaling AI initiatives require a systemic approach supported by evidence-based practices, student learning data, and the perspectives of both students and educators in decision-making. Future research in Saudi Arabia could examine long-term data documenting the growth of students' critical thinking skills in AI-enhanced learning environments. Qualitative studies exploring students' and teachers' perceptions of AI would also provide valuable insights. Additionally, culturally informed AI tools should support bilingual education and provide mathematics-relevant contexts grounded in local practices. By responsibly incorporating AI into mathematics classrooms, Saudi schools can cultivate a generation of confident, independent, and critical thinkers. Emphasizing innovation, equity, and evidence-based practices can help Saudi Arabia move beyond quick-fix solutions and realize the transformative potential of AI in education.

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