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Collaboration, Creativity and Compassion in a Digital Society

A proposal for a student-centred framework for critical thinking with Generative AI in mathematics education

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Generative artificial intelligence (GenAI) is reshaping mathematics education by providing students with immediate access to explanations, worked examples, and problem-solving support. While these capabilities offering opportunities to enrich learning, they also raise concerns about how students develop critical thinking when AI-generated solutions are readily available. The use of GenAI is increasing in Bhutanese schools but little is known about how teachers and students currently use these technologies in mathematics classrooms or what pedagogical challenges limit their effective integration. This conceptual paper proposes a mixed-methods study to identify the opportunities, challenges, and pedagogical gaps associated with the use of GenAI in mathematics education, using Bhutanese secondary schools as the study context. Guided by a pragmatic paradigm, the study will employ questionnaires with quantitative and qualitative components to explore current practices, perceptions, and experiences of teachers and students. The findings will inform the development of a contextually relevant pedagogical framework that positions GenAI as a cognitive scaffold for analysing mathematical problems, evaluating alternative solution strategies, and strengthening critical thinking. By establishing an evidence base before framework design, the proposed study aims to support the responsible integration of GenAI into mathematics education and provide direction for future research, curriculum development, and classroom practice.

Keywords: Generative artificial intelligence, critical thinking, mathematics education, human-AI collaboration, pedagogical framework

Introduction

Generative artificial intelligence (GenAI) has the potential to change how students learn mathematics and can contribute to higher-order learning when it is embedded within purposeful pedagogical activities that require learners to analyse, evaluate, and justify mathematical reasoning instead of accepting AI-generated responses uncritically (Lim et al., 2023). Teacher-guided interaction with GenAI has been associated with inquiry-based learning, collaborative problem solving, and deeper conceptual understanding, highlighting that learning outcomes depend on instructional design rather than on the technology itself. Nevertheless, much of the existing evidence has emerged from higher education or technologically mature contexts, with comparatively little attention given to secondary mathematics education in developing education systems. Within Bhutan, recent studies indicate that teachers and students are increasingly adopting tools such as ChatGPT, Copilot, and Gemini to support teaching and learning (Wangda, 2025; Wangdi & Rigdel, 2025). However, these studies have primarily examined perceptions and patterns of use rather than how GenAI can be pedagogically integrated to foster students' mathematical critical thinking skills.

To address this gap, this paper proposes a mixed-methods study to examine the current use of GenAI in Bhutanese secondary mathematics education and generate evidence to inform the development of a pedagogical framework for fostering critical thinking. The study seeks to answer three research questions:

RQ1: How are teachers and students currently using GenAI in secondary mathematics education in Bhutan?
RQ2: What opportunities and challenges do teachers and students perceive in using GenAI to support mathematical reasoning and critical thinking?
RQ3: What pedagogical considerations emerging from these findings can inform the design of a contextually relevant framework for integrating GenAI to enhance critical thinking in mathematics education?

By establishing an empirical understanding of current practice before proposing pedagogical solutions, this study aims to contribute a foundation for the responsible integration of GenAI into mathematics education and guide future research and classroom innovation.

Pedagogical context and design considerations

Critical thinking develops through active engagement with mathematical reasoning rather than through access to information alone. Exploratory learning environments that incorporate large language models encourage learners to interpret evidence, question AI-generated explanations, and construct their own understanding instead of accepting responses uncritically (Luo et al., 2026). Human-AI collaboration has also been associated with greater learner participation and knowledge construction when teachers actively facilitate discussion and reflection rather than delegate instruction to AI systems (Lo et al., 2026). GenAI functions most effectively as a cognitive scaffold that complements, rather than replaces, human teaching. These findings reinforce an important pedagogical principle: technology alone does not develop critical thinking. Higher-order thinking emerges when learners analyse information, evaluate competing ideas, justify their decisions, and reflect on their reasoning within carefully designed learning environments. Bloom's revised taxonomy (Anderson & Krathwohl, 2001) provides a useful lens for understanding these cognitive processes because analysis, evaluation, and creation require students to engage with ideas beyond procedural recall. Equally important is the role of teacher scaffolding in guiding learners through questioning, feedback, collaborative discussion, and reflective dialogue. In mathematics education, this means that GenAI should not be viewed as an automated problem solver but as a resource that prompts students to examine mathematical reasoning, compare alternative solution strategies, identify errors, and defend their conclusions. The pedagogical challenge is therefore not simply integrating AI into classrooms but designing learning experiences that preserve students' cognitive engagement while benefiting from AI-supported learning.

Within Bhutan, the educational use of GenAI is increasing, with studies reporting that teachers and students are adopting tools such as ChatGPT, Copilot, and Gemini to support teaching and learning (Wangda, 2025; Wangdi & Rigdel, 2025). However, existing research has largely focused on perceptions of GenAI or its general educational applications rather than its role in mathematics pedagogy. There remains limited empirical evidence describing how teachers and students currently use GenAI to support mathematical reasoning, what pedagogical challenges they encounter, and what forms of guidance are needed to foster critical thinking in mathematics classrooms. Addressing these questions is an essential step before proposing pedagogical models or curriculum guidance. Consequently, this study adopts a mixed-methods approach to establish an evidence base that will inform the development of a contextually relevant pedagogical framework for integrating GenAI to enhance critical thinking in Bhutanese mathematics education. Table 1 shows the comparative analysis of global educational research findings and the Bhutanese context.

Table 1.
Comparative analysis of global educational research findings and the Bhutanese context

Theme	International evidence	Bhutanese context	Implications for the proposed study
21st-century learning	Personalised learning, immediate feedback and adaptive support are widely reported (El Fathi et al., 2025; Hönigsberg et al., 2025; Kim et al., 2025).	Early evidence indicates similar affordances are recognised by teachers and students (Wangda, 2025; Wangdi & Rigdel, 2025).	Examine how these affordances are currently used in mathematics classrooms and identify pedagogical requirements for supporting critical thinking.
Challenges	Concerns include overreliance on AI, plagiarism and reduced critical engagement (Chan & Hu, 2023; Yavich, 2025; Zhai et al., 2024).	Similar concerns have been reported in Bhutan (Wangda, 2025).	Identify classroom practices that encourage critical evaluation rather than passive dependence on GenAI.

Ethical considerations	Hallucinations, transparency and responsible use require teacher guidance (Rudolph et al., 2023).	Concerns focus on privacy and data security (Wangda, 2025).	Explore how teachers and students perceive responsible GenAI use and what guidance they require.
Critical thinking	Positive effects have been reported in higher education when GenAI is pedagogically integrated (Larionova et al., 2024; Zhao et al., 2025).	Research has largely examined perceptions rather than classroom practice and has been limited in scope (Wangda, 2025; Wangdi & Rigdel, 2025).	Investigate current pedagogical practices and identify design principles to inform a contextually relevant framework for mathematics education.

Establishing a student-centred pedagogical framework

To establish an evidence base for the development of a pedagogical framework, this study proposes a convergent mixed-methods design grounded in a pragmatic research paradigm (Creswell & Creswell, 2023). The proposed study will invite approximately 150 students in secondary education from each participating urban and rural school, together with teachers who teach these year levels. Separate but parallel student and teacher questionnaires will be used. For RQ1, closed-ended items will identify the GenAI tools used, frequency and purposes of use, mathematical activities, and teaching and learning strategies. Open-ended questions will allow teachers and students to describe additional ways they use GenAI in secondary mathematics education. For RQ2, Closed-ended items will be informed by the higher-order levels of Bloom's taxonomy and AI-driven Bloom's taxonomy framework of Lubbe et al. (2025) and GenAI mathematics literature, and will examine perceived opportunities for critical thinking behaviours alongside challenges such as inaccuracies, overreliance and reduced independent reasoning. Open-ended questions will capture additional experiences. RQ1 responses will be analysed using frequencies and percentages to describe the GenAI tools used, frequency of use, purposes, mathematical activities, and learning strategies. Chi-square tests will examine whether categorical patterns of use differ between groups. For RQ2, opportunities and challenges will be ranked using agreement percentages and mean scores, with standard deviations also reported. Where items are directly comparable, independent sample t-tests will compare reliable composite scores between urban and rural participants and between teachers and students. Open-ended responses will be analysed thematically to explain and extend the quantitative findings. The integrated findings will inform the development of a contextually relevant pedagogical framework that supports teachers in designing learning activities where GenAI functions as a cognitive scaffold for mathematical reasoning, reflective judgement, and critical thinking. This evidence-informed approach recognises that effective educational innovation begins with an understanding of existing classroom practices before proposing new models of teaching and learning. Following approval from the CQ University's Human Research Ethics Committee and Bhutan's Ministry of Education and Skills Development, an online survey link will be distributed to participating schools together with the relevant participant information sheets, parent or guardian consent forms, child or young person assent forms, and adult participating consent forms.

The proposed framework is intended to position GenAI as a cognitive scaffold that supports, rather than replaces, mathematical reasoning. Drawing on principles of higher-order thinking and teacher-guided learning, the framework will encourage students to engage critically with AI-generated responses through analysis, comparison, evaluation, and justification. Instead of treating AI-generated solutions as authoritative answers, students will be encouraged to examine alternative solution pathways, identify mathematical errors where they exist, compare AI reasoning with their own approaches, and defend their conclusions through discussion and reflection. Within this process, the teacher remains central in designing learning activities, facilitating dialogue, and guiding students' reasoning to ensure that GenAI contributes to deeper conceptual understanding rather than cognitive dependence.

The integrated findings from the quantitative and qualitative phases will inform the design principles underpinning the framework. Quantitative data will provide an overview of current patterns of GenAI use and perceived opportunities and challenges, while qualitative evidence will provide deeper insights into classroom practices, teacher expectations, and students' learning experiences. Together, these findings will identify the

pedagogical conditions necessary for responsible GenAI integration within mathematics education. Rather than prescribing a single instructional model, the resulting framework is intended to provide adaptable guidance that teachers can apply across different mathematical topics and classroom contexts while maintaining a focus on developing critical thinking.

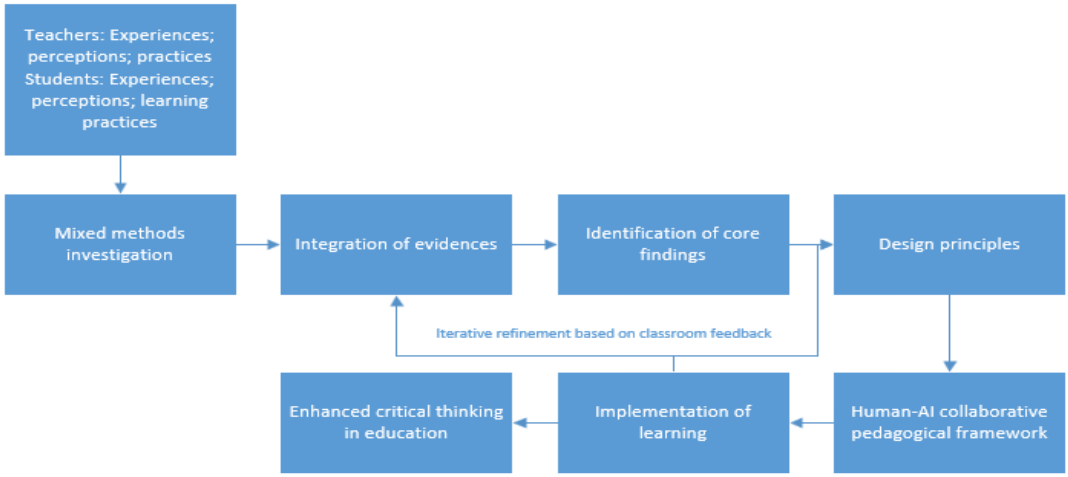


Figure 1. Preliminary conceptual pathway AI-human collaborative pedagogical framework in maths education

Figure 1 illustrates the proposed conceptual pathway linking the mixed-methods investigation with framework development. It demonstrates how evidence generated from teachers' and students' experiences informs pedagogical design, which subsequently guides the integration of GenAI into mathematics learning. This iterative process reflects the principle that effective educational innovation should emerge from classroom evidence and pedagogical need rather than from technological capability alone.

Towards student-centred learning design

GenAI can generate explanations, solve mathematical problems, and provide immediate feedback, these technological capabilities do not inherently foster critical thinking. Human-centred learning design provides a useful lens for addressing this challenge by emphasising that meaningful learning is shaped through purposeful pedagogical design, learner agency, and teacher facilitation rather than technological capability alone. The proposed study reflects this principle by placing teachers' and students' experiences at the centre of framework development. The mixed-methods investigation seeks to understand how GenAI is currently used within Bhutanese mathematics classrooms, the opportunities it creates, and the challenges that influence learning. This evidence-informed approach recognises that effective educational innovation should emerge from authentic classroom practices and the needs of learners and educators. By grounding framework development in empirical evidence, the study acknowledges that successful integration of GenAI depends on educational context, curriculum expectations, and the lived experiences of those who use the technology.

Within a student-centred learning design approach, GenAI is conceptualised as a cognitive scaffold rather than an autonomous tutor. Students remain active participants who are expected to analyse mathematical problems, compare alternative solution strategies, evaluate AI-generated responses, and justify their reasoning through teacher-guided dialogue. These learning activities position critical thinking as a process of inquiry and reflection rather than the production of correct answers. Equally important, the framework reinforces the teacher's role in orchestrating learning by designing questions, facilitating discussion, and supporting students in developing confidence to question AI-generated content. This balance between human judgement and technological support aligns with emerging perspectives that advocate responsible and pedagogically informed uses of GenAI in education (Lim et al., 2023). Although this proposal is situated within Bhutanese secondary mathematics education, its implications extend beyond a single educational system. Many schools are seeking ways to integrate GenAI without diminishing students' capacity for independent thinking. By proposing a systematic process that begins with understanding classroom practice before

designing pedagogical guidance, this study contributes to the growing discourse on human-centred learning design in AI-enabled education. The resulting framework has the potential to inform future research and support educators in designing mathematics learning experiences where GenAI enhances, rather than replaces, critical thinking.

Conclusion

This paper has argued that the educational value of GenAI depends not on the technology itself but on how it is integrated through thoughtful pedagogical design and outlines a mixed-methods study to identify the current use, opportunities, challenges, and pedagogical needs associated with GenAI use in Bhutanese secondary mathematics education. Table 1 demonstrates that while the educational potential of GenAI is increasingly recognised, important gaps remain regarding its pedagogical use to support critical thinking in mathematics education. As GenAI becomes increasingly integrated into secondary education, this study highlights the growing need for pedagogically grounded approaches that maximise its educational benefits while addressing challenges such as students' overreliance on GenAI, data privacy, and security.

The findings will inform the development of a contextually relevant pedagogical framework that supports teachers in using GenAI as a cognitive scaffold for strengthening students' critical thinking. By situating framework development within the principles of human-centred learning design, this proposal contributes a systematic and evidence-informed pathway for the responsible integration of GenAI into mathematics education. Future research will focus on developing, implementing, and evaluating the proposed framework in authentic classroom settings.

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