

CONTROVERSIAL ISSUES TO IMPROVE STUDENTS' MATHEMATICAL REASONING AND CRITICAL THINKING: A SYSTEMATIC LITERATURE REVIEW

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Abstract

The rapid development of education in the digital era and the Industrial Revolution 4.0 requires students to master higher-order thinking skills such as reasoning and critical thinking, which are essential for solving complex mathematical problems. This study aims to analyze and describe the role of controversial issues in developing students' mathematical reasoning and critical thinking skills. The research employed a Systematic Literature Review (SLR) with a descriptive qualitative approach. Articles were selected through a systematic search of Google Scholar, ResearchGate, Scopus, ERIC, and Web of Science using keywords related to controversial issues, mathematical reasoning, and critical thinking. The inclusion criteria consisted of national journal and international journal articles published between 2020 and 2025, focusing on mathematics learning contexts and discussing the relationship between controversial issues and higher-order thinking skills. A total of twenty relevant articles were selected and analyzed thematically to identify patterns related to controversial mathematical problems, reasoning processes, and critical thinking development. The results indicate that the integration of controversial issues in mathematics learning can stimulate constructive cognitive conflict, argumentative discussion, and reflective thinking, which contribute to the improvement of students' mathematical reasoning and critical thinking skills. Topics such as conceptual misconceptions, contextual mathematical problems, and socio-scientific issues encourage students to analyze information, evaluate arguments, and construct logical solutions. In addition, several studies highlight the important role of teachers in designing and facilitating controversial problem-based learning to optimize these cognitive processes. Overall, controversial issues provide an effective pedagogical approach for fostering reasoning, analytical thinking, and reflective judgment as essential competencies in 21st-century mathematics education.

Keywords: Controversial Issues, Mathematical Reasoning, Critical Thinking.

INTRODUCTION

The rapid development of education in the digital era and the Fourth Industrial Revolution requires students to possess higher-order thinking skills that go beyond conceptual mastery, including the ability to analyze, evaluate, and solve complex problems logically and reflectively. This demand is further reinforced by the emergence of the Society 5.0 era, which places humans at the center of technology-based decision making and emphasizes data literacy and adaptive thinking skills (Pujawan, 2023). In mathematics education, these competencies are closely related to

higher-level cognitive processes such as mathematical reasoning, critical thinking, and reflective judgment, which are considered essential components of 21st-century learning outcomes. Recent studies also highlight that the development of reasoning and critical thinking in mathematics plays a crucial role in enabling students to construct arguments, evaluate information, and justify solutions systematically (M. Wang et al., 2025);(Koh et al., 2025).

One learning approach that has the potential to stimulate these cognitive processes is the use of controversial

mathematical problems. Such problems are characterized by cognitive conflict, differing viewpoints, and the possibility of multiple interpretations or solutions, which require students to construct logical arguments, evaluate alternative reasoning, and clarify their understanding through discussion and reflection (Yanti et al., 2019). In this context, controversial issues function not only as problem situations but also as catalysts for deeper cognitive engagement. When students encounter conflicting information or divergent solution strategies, they are encouraged to justify their reasoning and critically evaluate the validity of different arguments (Rosyadi, 2021);(Suryawan & Ratnaya, 2023). Consequently, solving controversial mathematical problems simultaneously activates both critical thinking and mathematical reasoning processes.

Several empirical studies have shown that students who engage with controversial or open-ended problems demonstrate stronger higher-order thinking abilities than those who are only exposed to routine procedural questions. For instance, Suryawan & Ratnaya (2023) revealed that students' critical thinking processes in solving controversial mathematical problems can be mapped through the six IDEALS indicators (Identify, Define, Enumerate, Analyze, List, and Self-Correct), where the emergence of each indicator is strongly influenced by students' ability to analyze conflicting information within the problem context. Similarly, Turmuzi et al. (2023) reported that when solving controversial algebraic problems, students perform interconnected reasoning activities such as exploration, contradiction, reflection, and clarification. These findings indicate a close relationship between reasoning processes and the development of mathematical critical thinking skills.

Critical thinking skills in mathematics do not develop independently but are closely associated with reasoning abilities. Swastika et al. (2022) found that solving controversial or non-routine problems requires students to integrate reasoning processes with critical evaluation, including planning strategies, selecting solution steps, and verifying

results. Learners with stronger reasoning abilities tend to demonstrate higher levels of mathematical critical thinking performance when addressing complex or controversial mathematical situations (Suryawan, Nitiasih, et al., 2023). Furthermore, recent systematic reviews emphasize that argumentation, reasoning, and evaluation processes are central components of mathematical thinking that support students in constructing valid conclusions and justifying mathematical ideas (Lessing & Ogbonnaya, 2025);(Q. Wang & Abdullah, 2024).

The urgency of this research lies in the importance of presenting a comprehensive conceptual synthesis of the relationship between critical thinking and reasoning skills in the context of solving controversial mathematical problems. Although each of these skills has been extensively researched separately, there are still very few studies that integrate all three as a whole in the mathematical thinking process of students. In 21st-century learning practices, the real challenges faced by students require the simultaneous activation of various cognitive and reflective dimensions (Suryawan, Jana, et al., 2023). Therefore, this literature study was conducted to develop a theoretical framework that can be used as a basis for developing adaptive, innovative, and contextual learning strategies, especially in mathematics subjects that are oriented towards the formation of critical reasoning and higher-level problem solving.

Despite the growing body of research on mathematical reasoning and critical thinking, existing studies tend to examine these skills separately or focus primarily on specific instructional strategies. Only a limited number of studies explicitly analyze how controversial issues can function as an integrated pedagogical context that simultaneously activates reasoning and critical thinking processes in mathematics learning. In addition, previous reviews often concentrate on general instructional approaches for developing higher-order thinking without specifically mapping the conceptual relationship between controversial issues, reasoning processes, and critical thinking in mathematical

problem solving. This indicates a gap in the literature regarding a comprehensive synthesis that connects these three constructs within a unified framework of mathematical thinking.

Therefore, a systematic synthesis of empirical findings is needed to clarify how controversial mathematical issues can serve as a pedagogical mechanism for fostering both reasoning and critical thinking simultaneously. Understanding this relationship is important because real-world mathematical problems often involve ambiguity, multiple perspectives, and competing interpretations that require students to engage in reflective reasoning and critical evaluation (Romero et al., 2024). Integrating controversial issues into mathematics learning may provide opportunities for students to experience authentic argumentation processes, which are essential for developing analytical and reflective thinking competencies.

Based on this background, this study focuses on examining the role of controversial issues in improving students' mathematical reasoning and critical thinking skills. Specifically, this research aims to analyze and synthesize findings from recent studies to understand how controversial issues contribute to the development of these higher-order thinking skills in mathematics learning. Through a systematic literature review, this study seeks to map the conceptual relationships between controversial issues, reasoning, and critical thinking, as well as identify patterns of learning strategies that support their development.

In general, this study is expected to contribute both theoretically and practically. Theoretically, it provides a comprehensive synthesis that integrates controversial issues, reasoning processes, and critical thinking within the framework of mathematics education research. Practically, the findings may serve as a reference for teachers and educational institutions in designing learning strategies that emphasize argumentative discussion, reflective reasoning, and higher-order problem solving. Furthermore, this study can serve as a foundation for future research exploring

the implementation of controversial issues in mathematics learning across different educational levels and contexts.

METHOD

The research method used in this study was a literature study with a descriptive qualitative approach. This approach was employed to collect, analyze, and synthesize various relevant research findings regarding the role of controversial issues in developing students' mathematical reasoning and critical thinking skills over the last five years (2020-2025). The research design adopted a Systematic Literature Review (SLR) method, which aims to identify, evaluate, and synthesize findings from previous studies in a structured and transparent manner.

The research process began with the identification and formulation of research questions related to the role of controversial issues in mathematics learning and their relationship with students' mathematical reasoning and critical thinking skills. The literature search was conducted using several academic databases and scientific search platforms, including Google Scholar, ResearchGate, Scopus, ERIC, and Web of Science, which provide access to peer-reviewed journal articles, conference proceedings, and theses relevant to the research topic. To ensure a systematic search process, several keywords were used, including "controversial issues in mathematics learning," "mathematical reasoning," "critical thinking in mathematics," and "controversial mathematical problems." The search process was carried out by combining these keywords using Boolean operators such as AND and OR to obtain relevant literature.

After the initial search process, the identified literature was screened based on predetermined inclusion and exclusion criteria. The inclusion criteria for selecting literature in this study were: (1) articles published between 2020 and 2025, (2) studies that explicitly discuss controversial issues, mathematical reasoning, or critical thinking in mathematics learning, (3) articles available in full-text format, and (4) publications written in Indonesian or

English. Meanwhile, exclusion criteria included articles that were not directly related to mathematics learning, duplicate publications, or studies without clear research methods. Through this screening process, a total of twenty relevant articles were selected and used as the primary sources for analysis.

To ensure the credibility of the selected literature, a quality assessment process was conducted. Each article was evaluated based on several indicators, including the clarity of research objectives, the appropriateness of the research methodology, the relevance of the study to the research topic, and the completeness of the reported findings. Articles that met these criteria were then included in the final review. This process was intended to ensure that only studies with sufficient academic rigor and relevance were used in the synthesis.

The research subjects in this study consisted of various scientific articles discussing controversial issues, mathematical reasoning, and mathematical critical thinking. Because this study is literature-based, it does not involve a specific physical research location but instead focuses on digital academic documents obtained from the selected databases. Data collection techniques were carried out through systematic article searches, literature screening based on

inclusion criteria, and content analysis to identify data relevant to the research variables.

The data obtained from the selected articles were then analyzed using a thematic analysis approach. In this process, each study was reviewed in depth to identify key aspects such as research objectives, research methods, learning contexts, and findings related to the development of reasoning and critical thinking through controversial issues. These findings were then categorized into several main themes to facilitate the synthesis process. The research procedure followed the general stages of a Systematic Literature Review, which include: (1) identifying and formulating the research problem, (2) planning the literature search strategy, (3) selecting and evaluating relevant studies, (4) extracting important data from the selected articles, and (5) analyzing and synthesizing the findings descriptively.

The final result of this systematic review is a conceptual synthesis that illustrates the relationship between controversial issues, students' mathematical reasoning abilities, and their critical thinking skills. This synthesis is expected to provide a theoretical foundation for the development of more effective mathematics learning strategies that emphasize argumentation, reasoning processes, and reflective thinking.

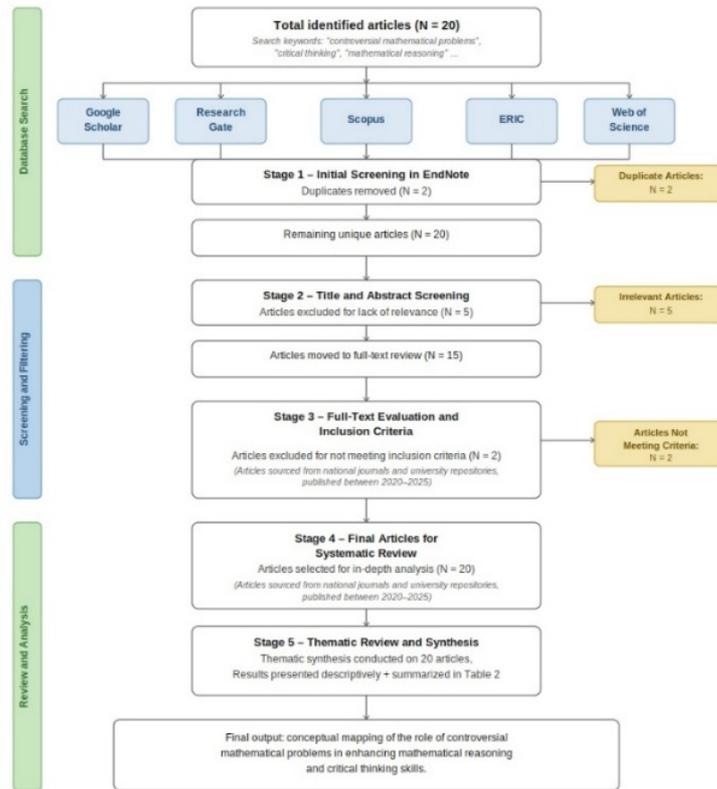


Figure 1. PRISMA Flow Diagram of Article Search and Selection Process

RESEARCH RESULT AND DISCUSSION

The results of this study were obtained through a systematic review of 22 articles discussing the application of controversial issues, mathematical reasoning, and critical thinking skills of students. The articles were collected through Google Scholar, ResearchGate, Scopus, ERIC, and Web of Science with a publication range of the last five years to ensure relevance to the current educational context. The identification and selection process was carried out based on inclusion criteria that included topic suitability, year of publication, and availability of the full text.

The review found that controversial issues contribute significantly to improving students' higher-order thinking skills, particularly in mathematical reasoning and critical thinking. The articles analyzed

included research on the development of learning tools, the implementation of controversial issues in the classroom, and studies on students' reasoning and critical thinking skills. To enrich the international perspective and strengthen the quality of the literature synthesis, seven additional sources were identified from internationally reputable indexed journals, including Scopus, ERIC, and Web of Science.

The synthesis of these studies revealed consistent evidence that controversial problems not only enhance students' logical reasoning but also stimulate reflective, evaluative, and metacognitive thinking processes. The meta-results of the reviewed studies are summarized in Table 1, which outlines the key findings, research methods, and theoretical frameworks employed in each study.

Table 1. Meta-Results of Controversial Mathematical Problem Studies and Their Role in Developing Mathematical Reasoning and Critical Thinking

No.	Author (Year)	Research Method	Focus/Indicators Used	Main Findings Related to Reasoning and Critical Thinking
1.	Rosyadi (2021)	Descriptive Qualitative	IDEALS critical thinking indicators (Identify, Define, Enumerate, Analyze, List, Self-correct)	Controversial problems stimulated reflective reasoning and integration of analysis–listing stages in students’ argumentation.
2.	Ramadhani et al. (2023)	Literature Study	Contextual reasoning and cultural-based critical sensitivity	Ethnomathematics enhanced contextual reasoning and openness to diverse viewpoints related to controversial problem-solving.
3.	Khamdani et al. (2023)	Literature Review	HOTS indicators: analysis, synthesis, evaluation	HOTS-oriented instruction fostered critical reasoning and logical evaluation during problem-solving.
4.	Utomo et al. (2020)	True Experiment (PBL–SSI)	Facione’s critical thinking indicators	Socio-scientific PBL improved critical analysis and reasoning through controversial contextual issues.
5.	Suryawan & Ratnaya (2023)	Descriptive Qualitative	IDEALS framework	Students demonstrated strong reasoning, justification, and reflective evaluation during controversial problem solving.
6.	Arjudin et al. (2022)	Workshop & Focus Group	Designing critical problem indicators	Teachers trained to design open-ended controversial problems promoting logical reasoning.
7.	Kristiana et al. (2022)	R&D (Guided Inquiry–SSI)	Analytical reasoning indicators	Guided Inquiry with SSI enhanced critical reasoning through discussion and justification.
8.	Nurwidodo et al. (2021)	Descriptive Analytic	Critical–creative–collaborative indicators	Environmental controversies encouraged reflective and ethical reasoning.
9.	Oktavia (2022)	Quasi Experiment	KADIR Model Indicators	KADIR with PhET simulations promoted analytical discourse and mathematical critical reasoning.
10.	Yuspitasari (2023)	R&D (ADDIE)	Argumentation-based critical thinking	E-LKPD SSI media facilitated identification, analysis, and justification in controversial problem-solving.
11.	Nofrianto (2021)	R&D (LKPD–SSI)	Analytical reasoning skills	Open-ended SSI worksheets encouraged data analysis and logical reasoning.
12.	Susiswo et al. (2022)	Descriptive Qualitative	Perceptual reasoning indicators	Prospective teachers demonstrated diverse logical reasoning when facing ambiguous mathematical problems.
13.	Walida et al. (2024)	Descriptive Study	Stages of controversial reasoning: exploration, contradiction, reflection, clarification	Students exhibited sequential reasoning patterns reflecting critical mathematical thought.
14.	Swastika et al. (2022)	Descriptive Qualitative	Metacognitive–reasoning indicators	Irrational controversial tasks developed reflective and evaluative reasoning.
15.	Pujawan (2023)	Descriptive Qualitative	Integrative reasoning and creativity indicators	STEAM-based controversial issues fostered logical reasoning and higher-order critical thinking.
16.	(Q. Wang &	Systematic Literature	Instructional intervention	Systematic review of 43 studies confirmed that diverse instructional strategies,

No.	Author (Year)	Research Method	Focus/Indicators Used	Main Findings Related to Reasoning and Critical Thinking
	Abdullah, 2024)	Review (PRISMA)	indicators for CT in higher mathematics (Ennis, Facione, Bloom)	including problem-based and inquiry learning significantly enhanced critical thinking in mathematics at the university level.
17.	(Niyazova et al., 2022)	Descriptive Qualitative & Curriculum Analysis	Open-ended problem classification indicators; academic motivation and reasoning	Classification of open and controversial mathematical problems showed significant effects on academic achievement and learning motivation; non-standard problems deepened students' reasoning strategies.
18.	(Asmoro et al., 2021)	Quasi-Experimental	Facione's CT indicators; argumentation and justification in mathematics	Structured problem-solving using open-ended controversial tasks significantly improved students' argumentation and logical justification skills compared to conventional learning.
19.	(Viehmann et al., 2024)	Scoping Review	SSI-based reasoning: complexity, perspective-taking, inquiry, scepticism	SSI pedagogical approach promotes interdisciplinary critical reasoning across STEM subjects; controversial issues deepen ethical and analytical thinking and strengthen scientific literacy.
20.	(Hjelte et al., 2020)	Systematic Review	Mathematical reasoning types: imitative, creative, and critical reasoning	Identified key types of mathematical reasoning addressed in empirical research; creative and critical reasoning were most strongly linked to non-routine and open-ended problem contexts.

To gain deeper insights into the synthesized findings, a thematic analysis was conducted to identify the dominant discussion topics, implications, and potential research gaps found across the reviewed studies. The analysis revealed recurring patterns concerning the use of controversial mathematical problems, the application of critical thinking indicators (Ennis and

Facione), and the integration of problem-based and socio-scientific approaches. In addition, several limitations were observed, including a lack of longitudinal evidence and limited teacher training in designing controversial problem-based tasks. The summary of major discussion themes, their implications, and opportunities for further study is presented in Table 2 below.

Table 2. Summary of Discussion Topics and Opportunities for Further Study

No.	Main Discussion Themes Found in the Reviewed Articles	Analysis of Implications and Limitations	Opportunities for Future Research
1.	Integration of Controversial Problems in Mathematics Learning	The majority of reviewed articles highlight that controversial problems effectively stimulate students' critical reasoning and reflective thinking. However, most studies are descriptive and limited to small samples, making it difficult to generalize their effectiveness across educational levels.	Future studies should experimentally examine the long-term effects of controversial mathematical problems on reasoning and critical thinking across different education levels.

No.	Main Discussion Themes Found in the Reviewed Articles	Analysis of Implications and Limitations	Opportunities for Future Research
2.	Critical Thinking Indicators Referenced from Ennis and Facione	80% of the reviewed works adopt Ennis and/or Facione’s critical thinking indicators, yet variations exist in interpretation and implementation. Some studies combine both frameworks without evaluating indicator consistency.	Further research should test the reliability of combined Ennis–Facione indicators and develop a localized set of critical thinking indicators for mathematics contexts.
3.	Problem-Based and Socio-Scientific Issue (SSI) Approaches	Problem-Based Learning (PBL) and SSI-based learning appear dominant (over 70% of reviewed articles). These approaches promote active discussion and argumentation but often lack clear alignment between tasks and assessment indicators.	Future studies should explore hybrid learning models combining PBL, SSI, and controversial problem-solving to strengthen analytical and evaluative reasoning.
4.	Role of Technology and Digital Tools	Only a small number of studies integrate digital simulations (e.g., PhET, E-LKPD). While they enhance engagement, evidence of their impact on reasoning depth remains limited.	Further research should analyze the use of digital simulations and AI-based tools in developing mathematical reasoning during controversial problem-solving.
5.	Teacher Competence and Material Design	Studies (e.g., Arjudin et al., 2022) indicate that teachers often struggle to design controversial mathematical problems due to limited training and resources.	Future research could focus on developing teacher training modules and instructional design frameworks for creating high-quality controversial mathematical tasks.
6.	Integration with 21st-Century Skills (HOTS, Collaboration, Communication)	Most reviewed works mention higher-order thinking skills (HOTS) but lack detailed frameworks linking controversial problems to collaboration, creativity, and communication skills.	Upcoming studies should operationalize how controversial problems foster integrated 21st-century competencies through collaborative and inquiry-based learning environments.

The Role of Controversial Issues in Developing Mathematical Reasoning

In general, controversial issues have been proven effective in fostering mathematical reasoning. Such issues require students to think logically, systematically, and reflectively because they contain cognitive conflicts that require in-depth analysis. Students are encouraged to evaluate information, identify

contradictions, and construct conceptual relationships in order to find justifiable solutions.

Research by Rosyadi (2021) shows that students who work on controversial problems display more complex reasoning patterns through stages of analysis and reflective clarification. These findings illustrate that the cognitive conflict arising from controversial issues encourages

students to not merely apply routine procedures, but to develop more in-depth and structured reasoning strategies. Students engage in a thinking process that requires evaluating various possible solutions, testing logical consistency, and reflecting on the decisions made at each stage of problem solving.

This finding is reinforced by Walida et al. (2024), who identified four stages of mathematical reasoning in solving controversial problems, namely exploration, contradiction, reflection, and clarification. The exploration stage reflects students' efforts to gather information and understand the structure of the problem as a whole. In the contradiction stage, students identify inconsistencies or contradictions in their initial understanding, which then triggers the need for further evaluation. The reflection stage involves reviewing the assumptions and strategies that have been used, while the clarification stage directs students to develop coherent and mathematically accountable solutions. These four stages form an iterative and mutually reinforcing cycle of reasoning, which not only produces a final answer but also enriches students' conceptual understanding.

In addition, research by Kristiana et al. (2022) developed guided inquiry-based learning tools and socio-scientific issues that have been proven to encourage students to construct mathematical arguments logically through discussion and justification of solutions. The guided inquiry approach provides scaffolding that helps students direct their own investigation process, while the integration of socio-scientific issues provides an authentic context that makes mathematics learning more meaningful. Through group discussions and argument presentations, students are trained to articulate their thoughts, listen to others' perspectives, and defend or revise their opinions based on strong mathematical evidence. This process not only develops mathematical reasoning but also communication and argumentation skills that are essential in 21st-century learning.

Arjudin et al. (2022) found that teachers trained in developing controversial questions were able to design learning

scenarios that developed mathematical reasoning through open discussion. This finding underscores the importance of teachers' capacity to identify controversial potential in mathematical content and design questions that can spark productive discussion. Trained teachers are able to facilitate a learning environment where students feel safe to express their ideas, even when those ideas are still in the developmental stage or potentially contain conceptual errors. Well-facilitated open discussions allow students to negotiate meaning, test hypotheses, and collectively build a stronger understanding of mathematical concepts.

Meanwhile, research by Nofrianto (2021) and Oktavia (2022) developed learning media based on PhET Simulation and LKPD with a Socioscientific Issues (SSI) approach, which proved effective in stimulating students' mathematical reasoning. The use of digital simulations such as PhET provides visual and interactive representations of mathematical concepts, which help students build stronger intuition and conceptual understanding. Students can manipulate variables, observe patterns, and test their predictions in a responsive environment. When combined with controversial socioscientific issues, these simulations become powerful tools for developing mathematical reasoning in authentic contexts that are relevant to real life.

The findings of Swastika et al. (2022) and Susiswo et al. (2022) confirm that logical contradictions in controversial issues require students to develop solutions with sharper reasoning. Logical contradictions serve as cognitive perturbations that encourage students to question their assumptions, identify errors in their reasoning, and reconstruct their understanding based on more solid evidence and logic. This process involves high metacognitive activity, where learners must monitor and regulate their own thinking processes. Meanwhile, Pujawan (2023) highlights the effectiveness of the STEAM approach based on controversial issues in shaping logical and collaborative reasoning. The STEAM approach integrates various

disciplines, allowing students to see how mathematical reasoning contributes to solving complex and multidimensional problems, as well as how it interacts with other modes of thinking such as design thinking, scientific experimentation, and artistic expression.

These findings are further corroborated by international studies. Hjelte et al. (2020) that creative and critical mathematical reasoning were most prominently activated in non-routine and open-ended problem contexts, precisely the type that controversial issues represent. Similarly, Niyazova et al. (2022) found that the classification and integration of open-ended and non-standard mathematical problems directly improved students' academic motivation and deepened their reasoning strategies. These international findings align with the Indonesian studies reviewed and strengthen the generalizability of the conclusion that controversial issues are a reliable catalyst for mathematical reasoning development.

Contribution of Controversial Problems to Mathematical Critical Thinking Skills

The results of the study also show that controversial problems play an important role in developing mathematical critical thinking skills. These critical thinking skills include evaluating solution strategies, identifying hidden assumptions, and constructing logical and evidence-based arguments. Astawan et al. (2023) define critical thinking as a directed and controlled intellectual activity to examine the accuracy, coherence, and relevance of information.

Research by Suryawan & Ratnaya (2023) found that solving controversial problems activates all IDEALS critical thinking indicators is Identify, Define, Enumerate, Analyze, List, and Self-correct, which encourage students to think systematically and reflectively. The Identify indicator involves the ability of students to recognize and formulate problems clearly. Define requires the ability to operationalize problems and identify relevant information. Enumerate includes the ability to generate various alternative solutions or perspectives. Analyze involves an in-depth examination of

each alternative, including identifying its strengths and weaknesses. List refers to the ability to develop explicit and rational evaluation criteria. Self-correct reflects the ability to revise thoughts and solutions based on new evidence or stronger arguments. The activation of all these indicators shows that controversial issues provide a rich context for developing comprehensive and integrated critical thinking skills.

This is in line with the results of Rosyadi (2021) research, which shows that analyzing and formulating logical reasons for answering controversial questions reflects the development of critical thinking skills. The process of building justifications for chosen solutions not only requires solid mathematical understanding, but also the ability to anticipate and respond to criticism, consider alternative perspectives, and communicate thoughts in a clear and persuasive manner. This activity develops intellectual dispositions that are important for critical thinking, including openness to new ideas, healthy skepticism toward unsupported claims, and a commitment to the pursuit of truth based on rational arguments.

Research by Khamdanah et al. (2023) confirms that the Higher Order Thinking Skills (HOTS) approach, which emphasizes analysis, evaluation, and synthesis, supports the strengthening of critical thinking in solving controversial problems. The HOTS approach provides an explicit framework for developing higher-order cognitive skills that go beyond simple understanding and application. In the context of controversial issues, analysis helps students break down problems into simpler components and identify the relationships between them. Evaluation allows students to assess the quality of information, the validity of arguments, and the effectiveness of solutions based on rational criteria. Synthesis encourages students to integrate various perspectives, information, and concepts into new, more complex understandings and innovative solutions.

In addition, Utomo et al. (2020) showed that the application of Problem-Based Learning based on Socio-Scientific Issues (SSI) can improve critical thinking

skills through investigation of controversial real-world issues. Problem-Based Learning (PBL) places authentic problems as the driver of learning, where students actively identify what they need to know, seek relevant information, and develop solutions. When the problems used are controversial socio-scientific issues, students are confronted with the complexity of the real world, which involves scientific, ethical, social, and economic considerations. This context requires the use of critical thinking not only to understand the mathematical aspects of the problem, but also to weigh competing values and make informed decisions.

Research by Yuspitasaki (2023) and Nofrianto (2021) also shows that SSI-based digital media is effective in encouraging students to identify issues, present arguments, and reflect on their solutions. Digital media offers unique affordances for controversial issue-based learning. Students can access various sources of information, collaborate with their peers online, and use digital tools to analyze data and visualize information. The digital format also allows students to revise and refine their thinking iteratively, as well as reflect on their thinking process through electronic journals or digital portfolios.

Another study by Ramadhani et al. (2023) shows that ethnomathematics-based learning fosters critical thinking through the introduction of various cultural perspectives that have the potential to spark conceptual debates. Ethnomathematics recognizes that mathematical practices are culturally situated and that different cultures have developed different ways of doing mathematics. When students are introduced to this diversity, they are confronted with fundamental questions about the nature of mathematical knowledge, the universality of mathematical concepts, and the relationship between mathematics and cultural context. These questions are inherently controversial and require deep critical thinking about the epistemology of mathematics and its implications for learning and teaching.

Meanwhile, research by Nurwidodo et al. (2021) shows that controversial environmental issues can develop reflective

and ethical thinking skills. Environmental issues such as climate change, resource conservation, and pollution often involve ethical dilemmas and complex trade-offs. Students must consider not only the technical and mathematical aspects of the problem, but also the long-term implications of various actions, the distribution of costs and benefits among different groups, and moral responsibility towards future generations. This context develops critical thinking that is not only logical and analytical, but also reflective and ethical.

At the undergraduate level, Susiswo et al. (2022) demonstrated that solving controversial problems helps prospective teachers evaluate their problem-solving strategies and develop critical assessments of their answers. For prospective teachers, the ability to think critically about mathematics is essential because they need not only to understand mathematical content, but also to anticipate students' misconceptions, evaluate the quality of mathematical explanations and representations, and design learning experiences that develop strong conceptual understanding. The experience of solving controversial problems provides prospective teachers with insight into how students might think about mathematical problems and what pedagogical strategies can be used to facilitate deep learning.

Swastika et al. (2022) obtained similar results, showing that irrational questions with controversial elements can stimulate deep metacognitive thinking processes. Metacognitive thinking, awareness and regulation of one's own thinking processes is an essential component of critical thinking. When students encounter challenging and controversial problems, they are forced to monitor their understanding, identify when they are confused or make mistakes, and adjust their strategies. These metacognitive activities not only improve performance on current tasks but also develop long-term capacity for self-directed learning and effective problem solving.

These conclusions are substantiated by several internationally reputed studies. Q. Wang & Abdullah (2024) confirmed that diverse instructional strategies especially

those involving problem-based and controversial contextual tasks significantly enhance students' critical thinking in higher education mathematics. Viehmann et al. (2024) that SSI pedagogy promotes interdisciplinary critical reasoning and strengthens scientific literacy, underscoring its generalizability beyond science education. Taken together, these international sources provide robust cross-cultural validation for the core claim that controversial mathematical problems serve as an effective and evidence-based vehicle for developing critical thinking.

Discussion

Based on the results of the literature review, it can be concluded that controversial issues play a significant role in developing students' mathematical reasoning and critical thinking skills. The cognitive conflict contained in controversial issues triggers reflective, analytical, and evaluative thinking processes. Students are encouraged not only to understand mathematical concepts procedurally, but also to use them in contexts that require logical and argumentative reasoning.

Cognitive conflict, which is the main characteristic of controversial issues, serves as a catalyst for conceptual change and the development of deeper understanding. Piaget's constructivist theory emphasizes that learning occurs through a process of assimilation and accommodation. When learners encounter information or situations that do not fit their existing cognitive schemas, an imbalance or disequilibrium occurs that motivates them to reconstruct their understanding. Controversial issues, with their ambiguous, conflicting, or differing perspectives, systematically create this disequilibrium, encouraging learners to engage in a process of equilibration that leads to a more sophisticated and integrated understanding.

In the context of mathematics education, where content is often taught procedurally without sufficient emphasis on conceptual understanding, controversial problems offer a powerful alternative. Instead of following a predetermined algorithm, students must analyze the

situation, consider various approaches, evaluate the validity of arguments, and justify their choices. This process not only develops stronger mathematical reasoning, but also builds a deeper conceptual understanding of why certain procedures work and when their use is appropriate.

Findings from various studies show that controversial issue-based learning helps students construct knowledge through a process of clarification, discussion, and deep reflection. This process enables students to develop more critical and systematic ways of thinking. Thus, controversial issues serve not only as an evaluation tool, but also as an effective pedagogical strategy for developing higher-order thinking skills.

The Vygotskian perspective on social learning provides a strong theoretical framework for understanding why controversial problem-based learning is so effective. Vygotsky emphasized the importance of social interaction and dialogue in the development of higher-order cognitive skills. In the context of controversial issues, the discussions and debates that occur among learners create a zone of proximal development in which learners can reach a level of understanding that they cannot achieve individually. Through the process of articulating their thoughts, listening to others' perspectives, and negotiating a shared understanding, learners develop the ability to think in more complex and nuanced ways.

The process of clarification in controversial issue-based learning involves identifying and addressing misconceptions. When learners engage with issues that contain contradictions or ambiguities, they are forced to externalize their thoughts and receive feedback from teachers and peers. This process allows hidden misconceptions to become explicit and addressable. Reflection, on the other hand, involves metacognitive activities in which learners evaluate their own thinking processes, identify areas where their understanding is weak, and develop strategies to improve their learning.

The role of controversial issues as a pedagogical strategy is also in line with the principles of inquiry-based and problem-

based learning. In this approach, learning begins with authentic and challenging questions or problems, rather than with the delivery of information. Learners are actively involved in the investigation process, using their existing knowledge to develop new understanding. Teachers act as facilitators, providing scaffolding and support when needed, but allowing learners to have agency in their learning process.

However, it is important to note that controversial issue-based learning requires careful classroom management and skilled facilitation. Not all cognitive conflict is productive; if learners feel too frustrated or overwhelmed, they may disengage from learning. Teachers need to create a psychologically safe environment where learners feel comfortable taking intellectual risks, making mistakes, and expressing their

confusion. Teachers also need to provide appropriate scaffolding to ensure that challenges are within learners' zone of proximal development challenging enough to encourage growth, but not so difficult as to cause frustration.

Beyond recognizing the general effectiveness of controversial issues as a pedagogical approach, a deeper and more critical examination of the reviewed studies reveals a more nuanced picture. While the weight of evidence consistently supports the positive contributions of controversial issues to mathematical reasoning and critical thinking, the reviewed literature also exposes a number of structural limitations and contextual constraints that must be addressed before this approach can be widely and reliably implemented.

Table 3. Critical Analysis: Strengths, Limitations, and Pedagogical Implications of Controversial Issues in Mathematics Learning

Streghths	Limitations	Pedagogical Implications
Encourages cognitive conflict that triggers reflective and evaluative reasoning (Rosyadi, 2021);(Swastika et al., 2022).	Not all students are able to manage cognitive conflict independently; it has the potential to cause frustration without adequate scaffolding (Walida et al., 2024).	Teachers need to design gradual scaffolding and provide a psychologically safe discussion environment.
Activates critical thinking indicators comprehensively: analysis, evaluation, synthesis, and self-reflection (Suryawan & Ratnaya, 2023);(Khamdanah et al., 2023).	Most studies are descriptive qualitative with small samples; generalization across educational levels remains limited (Q. Wang & Abdullah, 2024).	Large-scale longitudinal experimental studies are needed to confirm effectiveness across different contexts.
Integrates relevant SSI contexts, thereby increasing student motivation and engagement (Utomo et al., 2020);(Niyazova et al., 2022).	Multidisciplinary controversial issues have the potential to obscure the mathematical focus if not properly directed.	Task design guidelines are needed to maintain a balance between SSI context and clear mathematical objectives.
Supports the development of 21st-century competencies: critical thinking, collaboration, communication, and problem solving (Pujawan, 2023)	Authentic assessment models capable of comprehensively measuring reasoning development are still limited (Hjelte et al., 2020).	Developing argument-based reasoning rubrics integrated with critical thinking indicators needs to become a research priority.
Effective across various approaches: PBL, SSI, Guided Inquiry, STEAM, and digital simulations (Kristiana et al., 2022);(Oktavia, 2022);(Viehmann et al., 2024).	Teachers' capacity to design high-quality controversial problems remains low and uneven (Arjudin et al., 2022).	Teacher training programs based on controversial task design need to be developed and systematically piloted.
Encourages metacognition: students monitor, evaluate, and regulate their own thinking	The lack of longitudinal studies means the long-term impact on mathematical reasoning and	Further research needs to include longitudinal designs to measure the sustained influence of

Streghths	Limitations	Pedagogical Implications
processes (Swastika et al., 2022);(Susiswo et al., 2022).	critical thinking cannot yet be confirmed.	controversial issues on students' cognitive development.

As shown in Table 3, the strengths of controversial issue-based learning are substantial and well-documented. The approach consistently activates higher-order cognitive processes, including analysis, evaluation, and metacognitive regulation precisely the skills that conventional procedural instruction tends to underemphasize. International evidence from Hjelte et al. (2020) and Q. Wang & Abdullah (2024) converges with Indonesian studies in confirming that non-routine and open-ended problem contexts are among the most effective vehicles for developing these skills.

However, a critical reading of the reviewed literature also reveals several important limitations that have not been sufficiently problematized in most of the reviewed articles. First, the dominance of descriptive qualitative designs present in over 60% of the reviewed studies means that the evidence base, while rich in description, is weak in causal inference. Most studies document that students engage in complex reasoning when confronted with controversial problems, but they do not adequately isolate the contribution of the controversy element per se from other instructional variables such as group work, teacher scaffolding, or task design quality. This methodological limitation significantly constrains the conclusions that can be drawn about the unique causal role of controversial issues in fostering reasoning and critical thinking.

Second, the reviewed studies reveal a significant gap in assessment literacy. While frameworks such as IDEALS, Facione's model, and HOTS indicators are widely adopted, the reviewed studies rarely evaluate whether these indicators are being measured validly and reliably in the context of controversial mathematical tasks. Suryawan & Ratnaya (2023) and Rosyadi (2021), for instance, both use the IDEALS framework, yet their operationalization of each indicator differs substantially, making cross-study

comparison difficult. This inconsistency calls for the development of a standardized, context-specific rubric that can assess reasoning and critical thinking in controversial mathematical problem-solving more systematically and comparably.

Third, the role of the teacher emerges as both a key strength and a critical limitation. Arjudin et al. (2022) found that teachers who received targeted training were able to design and facilitate controversial problem-based learning effectively. However, the same study also highlighted that most teachers lack the pedagogical content knowledge necessary to exploit controversial issues productively. This finding is particularly significant in the Indonesian educational context, where large class sizes, high-stakes assessments, and curriculum constraints often leave little room for open-ended inquiry. Without systemic investment in teacher professional development, the potential of controversial issues will remain unrealized for the majority of students.

Fourth, while digital tools such as PhET simulations and E-LKPD platforms have shown promise in supporting controversial issue-based learning, the evidence of their effect on reasoning depth as opposed to surface-level engagement remains limited. Nofrianto (2021) reported improvements in students' data analysis skills, but the mechanisms by which digital interaction translates into deeper critical reasoning have not been adequately theorized or empirically traced in the reviewed literature. Future research should develop clearer theoretical frameworks for understanding how specific features of digital tools mediate the development of mathematical reasoning in controversial contexts.

Fifth, the reviewed studies exhibit limited attention to equity and differentiation. Most studies report average-level findings across student groups, without examining whether controversial issue-

based learning is equally effective for students with different prior knowledge levels, learning styles, or socioeconomic backgrounds. Given that the approach relies heavily on verbal argumentation, discussion, and self-directed inquiry, it may inadvertently disadvantage students who are not fluent in academic discourse or who come from cultural backgrounds where open questioning is not normalized. Ramadhani et al. (2023) gesture toward this dimension through ethnomathematics, but a more systematic investigation of equity-related concerns is needed if the approach is to be considered a genuinely inclusive pedagogical strategy.

Sixth, the relationship between controversial issues and different mathematical content domains remains underexplored. The reviewed studies tend to concentrate on general problem-solving contexts without clearly distinguishing the role of controversy across different subfields of mathematics, such as statistics, geometry, or algebra. It is plausible that the effectiveness of controversial issues varies depending on the nature of the mathematical content involved for instance, statistical reasoning about contested real-world data may respond more readily to SSI-based approaches than abstract algebraic reasoning. Future research should map these domain-specific differences more precisely.

Overall, controversial issue-based learning is relevant to modern education because it encourages students to reason logically, think critically, and make decisions based on accountable evidence. The results of this study reinforce the understanding that integrating controversial issues into mathematics learning can be a strategic alternative in building 21st-century competencies that emphasize reflective, analytical, and rational thinking skills.

The 21st-century competency framework developed by various international organizations emphasizes the importance of skills that go beyond traditional content knowledge. These skills include critical thinking, problem solving, communication, collaboration, creativity, and innovation. Controversial issues, with their complex, multidimensional, and open-

ended nature, provide an ideal context for developing these skills in an integrated manner. Students not only learn mathematics, but also learn how to use mathematics as a tool to understand and solve complex real-world problems.

Furthermore, in an information age where students are inundated with conflicting data and claims, the ability to think critically and evaluate arguments is becoming increasingly important. Controversial issue-based learning prepares students to become critical consumers of information and informed decision makers. They learn not to accept claims at face value, but to question evidence, consider biases, and evaluate the quality of arguments.

The integration of controversial issues into mathematics learning also has the potential to make mathematics more relevant and meaningful to students. One of the biggest challenges in mathematics education is engagement with many students questioning the relevance of mathematics to their lives and seeing no purpose beyond getting good grades. Controversial issues, especially those based on socio-scientific or contextual issues relevant to learners' lives, can increase intrinsic motivation and engagement by showing how mathematics can be used to understand and influence the world around them.

The critical analysis conducted in this study also generates several concrete recommendations for practice and research. For practitioners, the priority should be on designing structurally sound controversial tasks-tasks that are genuinely ambiguous, require mathematical reasoning, and are aligned to specific critical thinking indicators. For researchers, the priority should be on moving from descriptive to experimental and longitudinal designs, and on developing valid assessment instruments capable of capturing the nuanced development of reasoning and critical thinking over time. For educational policy-makers, the findings underscore the need for systemic investments in teacher training programs that build both the content knowledge and pedagogical competence required to implement controversial issue-based learning effectively.

Finally, controversial issue-based learning aligns with broader educational goals of developing informed, engaged, and responsible citizens. In democratic societies, citizens are often confronted with complex issues that require an understanding of technical or scientific information, evaluation of competing arguments, and decision-making based on values and evidence. The experience of addressing controversial issues in an educational context prepares students for this role, developing not only cognitive skills but also a disposition to engage with complex issues thoughtfully and responsibly. However, as the critical analysis in this review makes clear, realizing this potential requires moving beyond enthusiastic endorsement to a more rigorous, systematic, and equity-conscious implementation of controversial issue-based pedagogy in mathematics classrooms.

CONCLUSION

Based on a systematic review of 22 articles drawn from Google Scholar, ResearchGate, Scopus, ERIC, and Web of Science, this study concludes that the integration of controversial issues in mathematics learning constitutes a well-evidenced and theoretically grounded strategy for developing students' mathematical reasoning and critical thinking skills. The reviewed studies consistently demonstrate that controversial problems whether grounded in socio-scientific issues, open-ended contextual tasks, ethnomathematics, or digital simulation-based environments function as catalysts for constructive cognitive conflict that activates higher-order cognitive processes including analysis, evaluation, synthesis, metacognitive regulation, and reflective self-correction. This conclusion is substantiated not only by Indonesian studies applying frameworks such as IDEALS, Facione's model, and HOTS indicators, but also by internationally reputed studies indexed in Scopus and Web of Science, which converge in confirming that non-routine, open-ended, and controversial problem contexts are among the most effective vehicles for developing critical and

creative mathematical reasoning across diverse educational settings. A critical analysis of the reviewed literature further reveals, however, that the current evidence base is constrained by the dominance of small-scale descriptive qualitative designs, inconsistent operationalization of critical thinking indicators across studies, limited attention to equity and differentiation, and insufficient longitudinal evidence limitations that must be systematically addressed before controversial issue-based pedagogy can be reliably generalized and implemented at scale.

In light of these findings, practitioners are encouraged to design structurally sound controversial mathematical tasks that are genuinely ambiguous, explicitly aligned to critical thinking indicators, and supported by graduated scaffolding and psychologically safe classroom environments that enable all students to engage productively with cognitive conflict. Educational institutions should incorporate these insights into the development of learning tools, curriculum frameworks, and teacher training programs that build the pedagogical content knowledge necessary for designing and facilitating controversial issue-based learning effectively. For researchers, this review strongly recommends a shift from descriptive toward experimental and longitudinal research designs, the development of standardized and context-specific assessment rubrics for measuring reasoning and critical thinking in controversial problem-solving, and greater attention to equity dimensions including the differential effectiveness of this approach across student ability levels, cultural backgrounds, and mathematical content domains. Collectively, these directions point toward a more rigorous, inclusive, and evidence-driven implementation of controversial issues as a strategic pedagogy for cultivating the higher-order thinking competencies that are central to 21st-century mathematics education.

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