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A Review of Toulmin's Argumentation in Mathematics dan Science Learning: Implementation, Impact and the Role of the Teacher

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Abstract: A Review of Toulmin's Argumentation in Mathematics dan Science Learning: Implementation, Impact and the Role of the Teacher. Objective: This review study aims to analyze and provide a complete study of the role of Toulmin's argumentation model in math and science learning **Methods:** This study uses a systematic literature review by following the PRISMA form. We found 396 documents on the Toulmin's argumentation model published in 2020-2024, which were collected through the Scopus database. After the screening process, 19 articles were selected for analysis using thematic analysis. **Findings:** The review findings show that Toulmin's argumentation model is flexible enough to be used in learning, either as an argumentation analysis tool or as part of an innovative learning design. The positive impact can be seen in improving students' critical thinking skills, conceptual understanding, reasoning, and justification abilities. In addition, teachers have a vital role in supporting students' argumentation. The teacher is a facilitator, guide, and feedback provider that helps students develop and effectively deliver arguments. **Conclusion:** This study confirms that Toulmin's argumentation is relevant to improving students' higher-order thinking skills. It highlights the need for professional development for teachers to optimally support argumentation-based learning and select the most appropriate ways of integrating scientific argumentation into learning practice.

Keywords: mathematics learning, role of teacher, science learning, student's skills, toulmin's argumentation.

▪ INTRODUCTION

Around the world, over the last ten years, the concept of scientific argumentation as a core competency and pedagogical practice has become more important in school science learning (Giri & Paily, 2020). Scientific argumentation is critical to development because it trains us to think scientifically, communicate, and act like scientists. It is thus widely recognized as a critical goal of science (Probosari et al., 2022). Argumentation is a cognitive tool that can formalize the science of reasoning (Almpani, 2022), which involves numerical and verbal reasoning, is also highlighted as an essential competency in college academic success (Luesia et al., 2023). Empirical data generated from experiments or investigations are required to support scientific argumentation (Chen et al., 2016; Erduran, 2018; Lazarou & Erduran, 2021; Osborne et al., 2019). Thomas suggests that developing written argument skills is essential to contemporary education in a democratic society (Thomas, 2022). Therefore, academic institutions need to focus on developing argumentation skills (Kuhn & Moore, 2015). Research studies identify argumentation as a crucial component of mathematics instruction (Conner et al., 2014; Erkek & Işıksal Bostan, 2019) and mathematics comprehension (J. Cervantes-Barraza et al., 2019; Krummheuer, 2015). A practical argumentation framework elucidates the connection between facts and the reasoning provided to support assertions while

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acknowledging the underlying implicit premises (Khambete, 2019). Argumentation techniques transpire in both formal settings, such as classrooms, and informal contexts (González-Howard & McNeill, 2019). In formal settings, argumentative techniques are typically presented systematically and are intricately linked to the subject matter being instructed. On the other hand, informal settings provide distinctive and priceless time and space for problem-based learning and cross-disciplinary activities, which are crucial for students to increase their ability to argue, mainly when synthesizing evidence from many sources(Zhao et al., 2023).

Arguments are described and examined by researchers using Toulmin's argumentation model. Toulmin states that an argument is composed of a claim (a statement whose integrity has been established), data (the facts upon which the claim is predicated), warrant (a rationale for using the data to support the claim), rebuttal (a statement that challenges the warrant), qualifiers (statements that demonstrate the certainty of a statement), and backing (support for the warrant that is typically unstated and relevant to the academic field) (Kaplan et al., 2021; Murdani et al., 2023; Wagner et al., 2014). Toulmin's argumentation model is advocated for elucidating the process of learning within the classroom (DemiRay et al., 2022). A literature review indicates that Toulmin's model has been employed as a framework for analyzing argumentative texts or as a pedagogical instrument to acquaint students with constructing robust argumentation structures, owing to the model's substantial analytical and explanatory capabilities for argumentation essays (Ramadhani et al., 2023) and for analyzing argumentation texts or as a pedagogical tool to familiarize students with developing rich argumentation structures due to the solid analytical and explanatory power of this framework for argumentation essays (Kazemi et al., 2021). Toulmin's paradigm in teacher education may effectively assist educators in enhancing their understanding of collective argumentation (Wagner et al., 2014). Toulmin's argumentation model offers a framework for explaining how arguments and supporting data support scientific claims (Lazarou & Erduran, 2021). Toulmin's argumentation model has been used in several studies to help students express their arguments or help science teachers implicitly organize their argumentation interventions (Lazarou & Erduran, 2021). Numerous research has employed Toulmin's argumentation model to assist students in articulating their points of view or to assist science instructors in subtly structuring their argumentation exercises (Lazarou & Erduran, 2021). For pupils to explicitly practice argumentation, they must practice it in argumentation and think or discuss it (Zhang & Browne, 2023).

The quality of classroom debate is influenced by the teacher's ability to help and direct students to speak collectively (Gomez Marchant et al., 2021). Argumentation skills are essential in science learning, so science educators must prepare prospective teachers with scientific argumentation skills by innovating learning (Kazemi et al., 2021). Scientific argumentation skills can help students understand scientific phenomena in everyday life using theories based on science literacy (Fakhriyah et al., 2022). In mathematics education, argumentation is critical because it provides characteristics that help understand and explain didactic phenomena (Kazemi et al., 2021) and because it has communicative (Ayalon & Hershkowitz, 2018; Toro Uribe & Castro, 2020), and rhetorical nuances (Castro et al., 2021). In the mathematics classroom, collective argumentation is usually characterized by students and teachers working together to prove the truth of a claim (Wagner et al., 2014). One of the functions of mathematical

argumentation is as a basis for expressing ideas accompanied by evidence and theoretical support by mathematical problems (Ramandani et al., 2024). Nonetheless, teachers' encouragement of students to talk is essential in teaching students mathematics (Conner, 2022). However, for many teachers, enabling productive mathematical discussions is problematic (Gomez Marchant et al., 2021).

In light of the growing body of research on argumentation, a systematic review is essential to assess the landscape, particularly with Toulmin's argumentation model in educational contexts. Prior investigations employing Systematic Literature Review have merely addressed the evolution of the teaching-learning process in science, emphasizing argumentation as a critical element, particularly in physics (Parra Zeltzer et al., 2024), They have also examined the advancement of argumentation theory in science education (Erduran et al., 2015), the attributes of tasks utilized, and the subjects investigated in research on mathematical argumentation in higher education (Kartika et al., 2024) Furthermore, they have explored the application and media development utilizing Toulmin's argumentation framework (Amiruddin et al., 2023) and recognized argumentation as a means for analyzing the arguments of students and lecturers, as well as a pedagogical strategy (Silva Carneiro et al., 2023). This systematic literature review fills the gap in previous studies by examining Toulmin's argumentation model, which reviewed and analyzed its implementation in mathematics and science learning, its impact on students' skills, and the role of teachers in supporting argumentation. This study's review questions (RQ) include: 1) How is Toulmin's argumentation implemented in math and science learning? (RQ1); 2) How does Toulmin's argumentation impact students' skills? (RQ2); and 3) What is the role of teachers in supporting students' argumentation? (RQ3).

▪ METHOD

Research Design

Systematic Literature Review (SLR) is used as a research method to explain and describe Toulmin's argumentation in learning that focuses on the stages of identification, collection, and selection of literature that correlates with the specified questions and makes a conclusion based on the findings obtained to answer the *review questions* (Kalogiannakis et al., 2021; Nursupiamin & Badjeber, 2022). SLR is a method of collecting data appropriate to a particular topic that meets predetermined eligibility criteria (Mengist et al., 2020). The review was conducted to present trends in research on Toulmin's argumentation in math and science learning and suggest possible future research.

Search Strategy

SLR in this study follows the preferred reporting items for systematic reviews and meta-analysis (PRISMA) model as presented in Figure 1, which has the *identification stage, the screening stage,* and the *included stage.* The article selection process was carried out using Watase UAKE software.

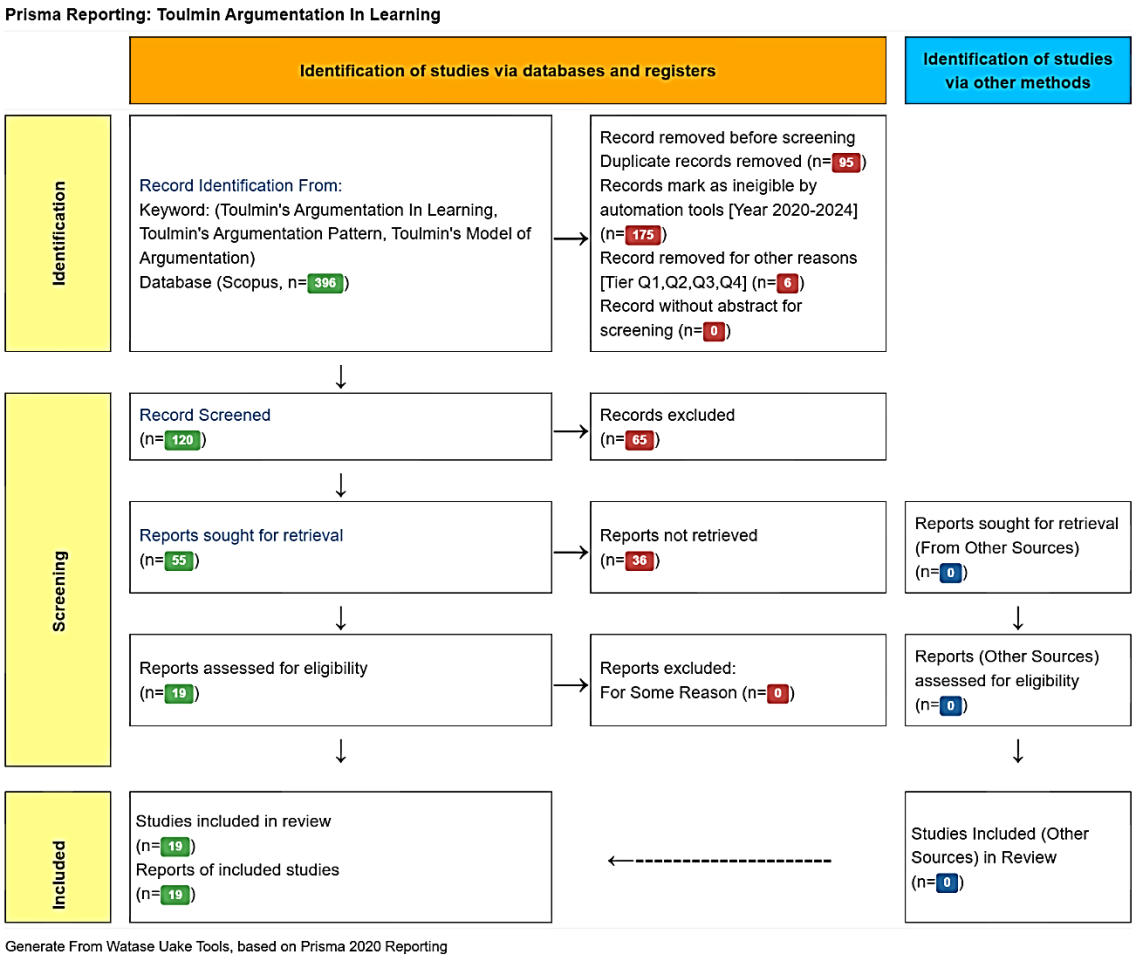

Figure 1. PRISMA flowchart

This study used an extensive document search to find pertinent and suitable material about Toulmin's argumentation in mathematics and science learning. Watase UAKE software was used to search with keywords such as 'Toulmin's AND argumentation AND in AND learning,' 'Toulmin's AND argumentation AND pattern,' or 'Toulmin's AND model AND of AND argumentation.' All searches were made against article abstracts through the Scopus database. We utilized the Scopus database to identify documents pertinent to the Toulmin argumentation study due of its extensive collection of electronically validated texts across several scientific disciplines (Zhu & Liu, 2020). We found 396 articles based on these search results, which consist of articles, conference papers, book chapters, reviews, books, etc. Results of the initial search can be found in Table 1.

Table 1. Result of initial research

Keywords	Database	Hits
Toulmin's Argumentation In Learning	Scopus	90
Toulmin's Argumentation Pattern	Scopus	86
Toulmin's Model of Argumentation	Scopus	220
Total		396

Inclusion and Exclusion Criteria

In order to be included in this review, studies needed to be peer-reviewed, published in a journal between 2020 and 2024 and written in English. The study also needed to address at least one of the review's research questions. Therefore, we set several inclusion criteria in screening articles. Firstly, the document's abstract had to contain the keyword "Toulmin argumentation". Secondly, the document was an article from a journal indexed by Scopus and published between 2020 and 2024. This is done to understand the current state of knowledge of the field under study and comes from credible data sources.After eliminating irrelevant and duplicate documents (95 article), we have 120 articles remaining. Thirdly, the document was only written in English. Fourthly, all articles selected were studies in maths and science learning. After checking and selecting according with this criteria, we found 19 articles eligible for review. The article selection process also considered the availability of full-text articles. To guard against bias, the co-author reviewed included and excluded articles against the criteria and confirmed that all retained articles met the criteria.

Data Analysis

Thematic analysis identifies, analyzes, and reports themes within the data. Braun and Clarke recommend six stages of thematic analysis (Margot & Kettler, 2019). Firstly familiarization with the data, secondly generating codes about Toulmin's argumentation study in math and science learning, thirdly generating themes, fourthly reviewing themes about research review questions, fifthly defining and naming themes, and sixthly creating the report.

▪ RESULT AND DISSCUSSION

RQ1 : How is Toulmin's argumentation implemented in math and science learning?

The first review question examines using Toulmin's argumentation model in math and science learning. Figure 2 shows that most articles (16 or 84,2%) discuss using Toulmin's argumentation model to analyze and describe the elements of students' argumentation in math and science learning (Alcock & Attridge, 2023; J. A. Cervantes-Barraza et al., 2020; DemiRay et al., 2022; Fakhriyah et al., 2022; Gomez Marchant et al., 2021; Kaplan et al., 2021; Komatsu & Jones, 2022; Lazarou & Erduran, 2021; Probosari et al., 2022; Ramadhani et al., 2023; Rodríguez-Nieto et al., 2023; Uygun, 2020; Zambak & Magiera, 2020; Zengin, 2022; Zhang & Browne, 2023; Zhao et al., 2023). Furthermore, three articles (15,8%) integrate Toulmin's argumentation in a particular learning method (Akhdinirwanto et al., 2020; Giri & Paily, 2020; Murdani et al., 2023). Vetti Gir and M. U. Paily employed Toulmin's argument pattern (TAP) within the framework of the Think-Read-Group-Share-Reflect (TRGSR) technique (Giri & Paily, 2020). The Problem-based Learning with Argumentation (PBLA) approach also uses Toulmin's argumentation. The five stages of this model are problem identification and motivation, organization and inquiry, preparation and investigation of the argument, argumentation session, and evaluation of the reflection. This approach assists students in analyzing facts, interpreting conclusions, and articulating responses through argumentation (Akhdinirwanto et al., 2020). The PABCSCHL model incorporates Toulmin's argumentation into its framework for physics argumentation-based computer-supported collaborative hybrid learning. The PABCSCHL model comprises reading (online), concept construction, offline discussion and argumentation, online experiment

design, and offline experiment execution (Murdani et al., 2023). In this methodology, students collaborate, engage in discourse, and conduct experiments.

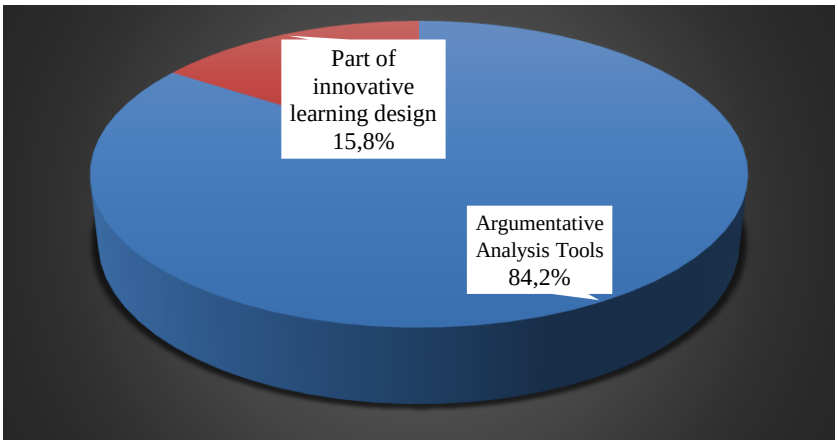

Figure 2. Distribution of studies based on the implementation of Toulmin's argumentation

This finding shows that Toulmin's argumentation model is a flexible approach to use in the learning process. This confirms the role of Toulmin's argument pattern as a relevant framework to support argumentation-based learning. Its flexibility allows integration in various learning contexts as an analytical tool, or as part of an innovative learning design. This finding is in line with several research results that Toulmin's Argumentation pattern has been used as a tool to analyze arguments in science education research (Dawson & Carson, 2020; Grimes et al., 2019; Koomen et al., 2018). Furthermore, owing to its logical clarity and precise argumentative components, Toulmin's argumentation model has been consistently adopted, refined, and effectively utilized in the instruction of several disciplines by educators and researchers in recent years (Yang, 2022). Toulmin's argument pattern (TAP) serves as a pedagogical heuristic to assist students in articulating their arguments or to aid scientific educators in systematically structuring their argumentation interventions, either directly or implicitly (Cebrián-Robles et al., 2018; Lin, 2018). Research findings demonstrate that "enhancements in argumentation can be achieved through explicit discussion and instruction" (Archila et al., 2020). This methodology is utilized to document and analyze student learning in mathematics education (Zengin, 2022). Consequently, researchers and educators continue to seek the most effective methods for incorporating scientific argumentation into educational processes (Zhang & Browne, 2023).

RQ2 : How does Toulmin's argumentation impact students' skills?

Seven articles discuss the impact of Toulmin's Argumentation model on students' skills. The findings obtained suggest that the integration of Toulmin's Argument Pattern (TAP) in the Think-Read-Group-Share-Reflect(TRGSR) strategy and problem-based learning model (PBLA) is efficacious in improving students' critical thinking skills (Akhdinirwanto et al., 2020; Giri & Paily, 2020). The application of the Physics Argumentation Based Computer Supported Collaborative Hybrid Learning (PABCSCHL) model in Socio-Scientific Issues learning and the Scientific Reading-based

Inquiry (SRbI) model, which incorporates the Toulmin Argument Pattern, can improve students' argumentation skills (Murdani et al., 2023; Probosari et al., 2022). In addition, using Toulmin's argumentation helps students reason, justify, and understand others' ideas in mathematical and scientific terms (Uygun, 2020), thus improving their conceptual understanding (Murdani et al., 2023; Uygun, 2020). Utilizing the Toulmin Argumentation model facilitated a rapid transformation in Pre-Service Teacher (PST) reasoning, wherein most PSTs transitioned from presenting unsupported claims to formulating deductive arguments characterized by explicitly articulated claims accompanied by substantiating evidence and rationale (Zambak & Magiera, 2020). Toulmin's extended argumentation model also helps students to identify patterns, make generalizations, and construct evidence with teacher guidance (J. A. Cervantes-Barraza et al., 2020). These results suggest that the Toulmin argumentation model can improve students' skills, including critical thinking skills, argumentation skills, conceptual understanding, reasoning and justification skills.

Toulmin's argumentation approach aids pupils in recognizing their assertions and determining how to substantiate them. The methodology aids students in formulating arguments, connecting claims to evidence, and prompts them to critically evaluate the acceptability of their argumentation to the reader (Yang & Pan, 2023). Argumentation is a practical approach to promoting theoretical understanding to support productive knowledge attainment (Larrain et al., 2019; Liu et al., 2019), constructing their ideas with the help of argumentation (Uygun, 2020) and the development of metacognitive skills (Reisoğlu et al., 2020). Understanding argumentation structure helps students express their views logically (O'Hallaron, 2014). The argumentation process also allows students to develop scientific knowledge from data and evidence and to understand scientific phenomena (Fakhriyah & Masfuah, 2021). Engaging in numerical and verbal thinking argumentation is a crucial skill for academic achievement in college (Luesia et al., 2023).

With the help of argumentation teaching, students can gain a better understanding of the relationship between evidence and statements. This can improve their critical thinking ability (Yang, 2022). Argumentation learning can also help students retain scientific knowledge (Yamtinah et al., 2019). Incorporating arguments, especially in organic chemistry, helps students understand concepts and think critically (Samani et al., 2019). Argumentation has been demonstrated to enhance comprehension and analytical skills in chemistry, while spatial ability is crucial for proficient argumentation (Pabuccu & Erduran, 2017). The purpose and use of arguments also aid the process of convincing and justification in mathematics; it is considered a functional component of proof construction (Zengin, 2022). In addition, as stated by Cetin (Cetin-Dindar et al., 2018), explicit argumentation Instruction is crucial for enhancing conceptual comprehension and argumentative skills. All types of arguments improve cognitive and metacognitive processes, communication skills, and critical reasoning abilities, so learning arguments in science classes can help students learn science (Zhao et al., 2023). Students' participation in science in the form of argumentation can help them think critically and reflect on and assess evidence (Bathgate et al., 2015). Therefore, scientific argumentation can potentially improve higher-order thinking skills and should be recognized as a challenge to implement in the classroom. Teachers should also be informed about argumentation pedagogy (Giri & Paily, 2020).

RQ3 : What is the role of teachers in supporting students' argumentation?

The last review question (RQ) discusses the role of teachers in supporting students' argumentation. Based on the results of the analysis, it was found that ten articles examined this matter. Teachers or instructors can influence the emergence of mathematical practices through proper instruction (Komatsu & Jones, 2022; Uygun, 2020). They act as facilitators, guides, co-learners, and navigators through the complex landscape of scientific argumentation and representation (Gomez Marchant et al., 2021; Ramadhani et al., 2023). Furthermore, teachers provide scaffolding if any group goes in a different direction than desired (DemiRay et al., 2022; Giri & Paily, 2020) and feedback to support students in learning activities (Zengin, 2022). Teacher-researchers also ask questions to encourage collective argumentation and help students express their arguments, which are then used to facilitate proofwriting (J. A. Cervantes-Barraza et al., 2020; Giri & Paily, 2020).

The teacher's involvement is essential in fostering and enhancing students' argumentation skills (Härmä et al., 2021). In the expansive realm of digital education, educators function as conveyors of knowledge and as guides who delineate the trajectory of discourse, ensuring its profundity and rigor (Lee, 2014). During the learning process, educators are responsible for integrating feedback, adjusting their methods to the evolving dynamics of the discourse, and enhancing their instructional strategies. Our study highlights the significance of professional development for educators (Ramadhani et al., 2023). The instructor's role is increasingly vital in online settings, where the lack of physical signs necessitates greater participation to cultivate meaningful exchanges and sustain discourse momentum (Putri et al., 2022). With the evolving landscape of online education, instructors must be equipped with the latest strategies and tools to effectively facilitate structured argumentation effectively (Clark et al., 2007; Siswanto et al., 2018). The outcomes of this study corroborate previous research, indicating that science educators actively modify instructional adjustments to TAPs (Dawson & Carson, 2020; Lin, 2018). Argumentation activities must not only provide replies but also offer comments and scientifically substantiate their claims (Probosari et al., 2017). Yackel posited that how educators enable and direct students in debate collectively influences the caliber of arguments within the classroom (Gomez Marchant et al., 2021). With the guidance of educators, students can develop mathematical proofs to substantiate the legitimacy of their assertions. (J. A. Cervantes-Barraza et al., 2020).

▪ CONCLUSION

This study provides an in-depth understanding of teachers' implementation, impact, and role in using Toulmin's argumentation model in math and science learning. Toulmin's argumentation model is flexible enough to be used in learning, either as an argumentation analysis tool or as part of an innovative learning design. The positive impact can be seen in improving students' critical thinking skills, conceptual understanding, reasoning, and justification abilities. In addition, the role of the teacher is vital in facilitating this process. The teacher is a facilitator, guide, and feedback provider that helps students develop and effectively deliver arguments. In the digital education era, this role extends to managing online discussions to ensure learning remains meaningful. This study confirms that Toulmin's argumentation is relevant to improving students' higher-order thinking skills. It highlights the need for professional development for teachers to optimally support

argumentation-based learning and select the most appropriate ways of integrating scientific argumentation into learning practice.

Research that can be developed from this study includes several relevant aspects to expand the application of Toulmin's Argumentation Model in learning. It is necessary to explore the integration of this model with other innovative learning methods to improve student learning outcomes optimally. In addition, longitudinal research is also needed to evaluate the long-term impact of this model on students' critical thinking skills, argumentation ability, and conceptual understanding. Furthermore, attention to teacher competence in implementing this model is crucial. Research could focus on developing teacher training to improve the effectiveness of Toulmin's argumentation-based learning across different subjects and education levels.

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