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STEM Approaches in Learning to Improve Students' Argumentative Skills: A Systematic Review of the Literature

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Abstract

Scientific argumentation skills are essential competencies in 21st-century learning, which not only reflect students' critical and analytical thinking abilities, but also become the foundation for evidence-based decision-making. In the context of science learning, the integration of STEM approaches is believed to be able to strengthen students' ability to build and evaluate scientific arguments in more depth. This study aims to conduct a systematic literature review (SLR) on various STEM-based learning media and approaches used to improve students' argumentation skills. The review process was carried out by following the PRISMA 2020 protocol, including searching articles from reputable databases such as Scopus, SpringerLink, DOAJ, and Google Scholar. The inclusion criteria include articles published between 2015 to 2025, indexed by scopus Q1-Q4, explicitly mentioning argumentation skills, and being in the context of STEM education. Out of a total of 277 articles identified, 40 articles were selected for further analysis. The results of the study revealed that approaches such as argument-driven inquiry (ADI), project-based learning (PjBL), socioscientific issues (SSI), and engineering design process (EDP), have consistently proven to be effective in improving the quality of students' arguments. Learning media such as digital scaffolding, interactive simulations, argumentative worksheets, and argument mapping are widely used to support the critical thinking process and argument structuring. In addition, real-issue based learning and experimental activities show a positive impact on students' ability to structure claims, reasons, and evidence in a structured manner. This study makes an important contribution in directing the development of STEM learning designs that explicitly support the strengthening of scientific argumentation skills. The practical implications of this study include the need for teacher training, the integration of argumentation rubrics in assessments, as well as the development of adaptive digital learning media.

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1. INTRODUCTION

Scientific argumentation skills are one of the main pillars in the development of science literacy and higher thinking in the context of 21st century learning. Scientific argumentation is not only concerned with the ability to express opinions, but also involves the formulation of claims based on evidence, logical reasoning , as well as an evaluation of the various viewpoints and evidence available. In an educational environment that increasingly emphasizes the importance of data-driven decision-making and complex problem-solving, argumentation skills are an integral part of a meaningful and contextual learning process (Osborne et al., 2004; Erduran & Jiménez-Aleixandre, 2007).

Specifically, in science learning, argumentation skills allow students to understand concepts more deeply by constructing valid, evidence-based explanations. Argumentative activities in science learning not only encourage students' cognitive engagement, but also develop scientific attitudes such as being open to dissent, skeptical of information that is not supported by data, and being able to evaluate the quality of arguments. Research shows that students who engage in argumentative activities tend to have stronger conceptual understanding and higher reflective abilities (Driver et al., 2000; Simon et al., 2006).

In the past two decades, the STEM (Science, Technology, Engineering, and Mathematics) approach has become a major focus in global education reform, including in Indonesia. This approach aims to integrate the four disciplines in a holistic, contextual, and problem-solving-oriented learning experience. STEM education emphasizes collaboration, exploration, creativity, and the development of innovative solutions through scientific and engineering methods (Bybee, 2013). In this context, argumentation skills are particularly relevant as students are challenged to build data-driven solutions, convey ideas logically, and defend their decisions through critical discussion and evaluation.

A number of learning models developed within the STEM framework have been proven to have the potential to improve students' argumentation skills. Argument-Driven Inquiry (ADI), for example, is an inquiry-based model that explicitly integrates argumentative activities into the process of scientific inquiry. In ADI, students not only conduct experiments, but also draft argumentative reports, revise arguments based on new data, and discuss openly. Studies have shown that ADI is able to improve the quality of students' arguments in terms of structure, clarity of reason, and evidentiary strength (Sampson et al., 2011; Şahin Kalyon & Yılmaz, 2025).

In addition to ADI, project-based learning (PjBL) and socio-scientific issues (SSI) are also important parts of STEM learning that can encourage the development of argumentation. In project-based learning, students are encouraged to design and implement solutions to real problems, which require them to make decisions, collect data, and present arguments to defend their designs or choices. Meanwhile, SSI-based learning raises controversial issues in science that contain social, ethical, and political dimensions, thus encouraging students to build arguments not only based on scientific data, but also considering moral and social viewpoints (Sadler, 2004; Kruit et al., 2024)

Although many studies have shown the potential of various STEM approaches in shaping argumentative skills, to date there have been no studies that have systematically examined the relationship between STEM approaches and students' argumentative skills. Previous studies tend to be individual, limited to specific contexts or approaches, and do not provide a comprehensive picture of the types of media and learning strategies used. In addition, meta-analysis studies that compare the effectiveness of various approaches in the context of science education are also still minimal, especially those that focus on argumentation skills as the main output.

Another gap that is still visible is the lack of practical guidance for teachers and learning designers to choose the most appropriate STEM approach in the development of student argumentation. Many teachers still face challenges in integrating explicit argumentative activities into STEM learning due to limited pedagogical knowledge and the availability of supporting media. Therefore, a systematic review is needed that not only maps the approaches and media that have been used, but also examines their effectiveness in different contexts (level of education, subjects, and types of argumentation skills developed).

Through this systematic study, researchers seek to fill this gap by filtering and analyzing the latest scientific articles that explicitly examine argumentation skills in the context of STEM learning. This research refers to the principles of systematic review by following the PRISMA 2020 protocol. The articles reviewed were selected based on strict inclusion criteria, including indexing in Scopus Q1–Q4, publications in the 2015–2025 range, and explicitly mentioning "argumentation skills" in the context of STEM-based education.

The results of this study are expected to make an important contribution to the development of STEM learning designs that explicitly target strengthening scientific argumentation skills. In addition, the results of this review can also be used as a basis for policy development, teacher training, and the development of media and assessments that are more relevant to the learning needs of the 21st century.

Based on this description, this research is focused on answering the following questions: "What media and approaches are used in STEM learning to improve students' argumentation skills?"

2. RESEARCH METHOD

This type of research is Systematic Literature Review (SLR), which is a literature review that is compiled in a systematic, comprehensive, and structured manner to identify, evaluate, and synthesize research findings relevant to the topic of argumentation skills in the context of STEM learning. This approach is used to summarize empirical evidence from various scientific sources in order to gain an in-depth understanding of the relationship between STEM approaches, learning media, and the development of student argumentation.

This research was carried out in the period from January to June 2025. The literature search and analysis process is carried out online through access to scientific databases available nationally and internationally. The research place is located at Jember State University, especially within the Science Education Study Program.

The target in this SLR is not an individual, but a research document in the form of a scientific article published in a journal. The subject of analysis is an article that explicitly discusses students' argumentation skills in the context of STEM learning. The population of articles is drawn from reputable databases such as Scopus, Springer Link, sage journals and Google Scholar. The inclusion criteria include articles published in 2015–2025, full-text, Scopus indexed (Q1–Q4), and research on elementary, junior high, high school, or pre-service teachers in the context of science or STEM education. Articles that are not available in full form, do not explicitly mention the argument, or focus on non-educational areas are excluded from the analysis.

The research procedure follows systematic stages based on the PRISMA 2020 protocol, which includes four main stages as follows: 1) Identification where the article is searched through an online database with the keyword "argumentation AND skills. 2) Screening where the initial screening process is carried out based on titles and abstracts. 3) Feasibility Assessment where it was issued because it did not meet the inclusion criteria. 4) Inclusion where additional articles are obtained from cross-references (manual search).

The data collected was in the form of article metadata: author's name, year of publication, title, type of STEM approach, learning media used, and key findings related to argumentation skills. The instrument used in data collection is a coding sheet that is compiled by researchers based on predetermined analysis categories.

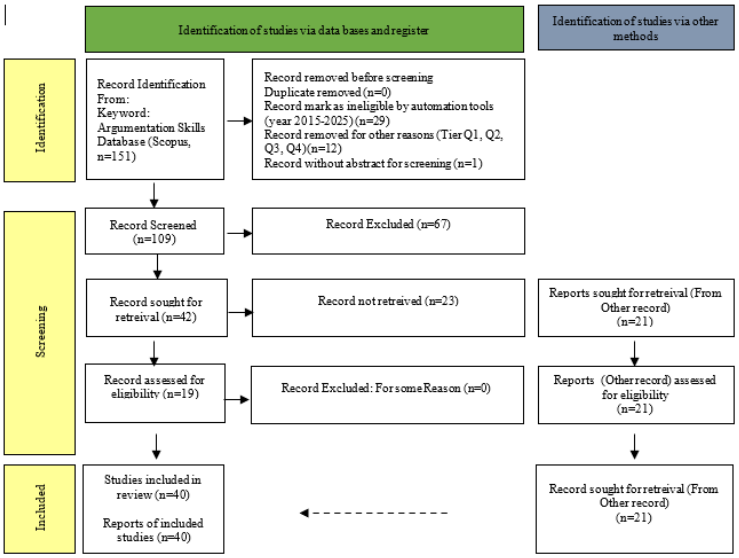
Data were analyzed using thematic techniques and narrative synthesis including the type of STEM approach (e.g., ADI, SSI, PjBL, EDP), the media or intervention used (e.g., simulation, worksheet, argument mapping), results or impacts on argumentation skills, the context of the students and the location of the study.

All data are compiled into a synthesis table to facilitate the identification of trends, gaps, and the effectiveness of the approach in strengthening arguments. This synthesis process aims to draw a thorough conclusion regarding how STEM approaches are used to develop students' scientific argumentation skills. The interpretation of the results is carried out by paying close attention to their relevance to the formulation of the problem and the objectives of the research.

3. RESULT AND DISCUSSION

This study analyzed 40 selected articles consisting of 19 main selection articles and 21 additional articles from manual search. The distribution of the publication year shows that research on argumentation skills in the context of STEM learning has increased significantly in the past decade, especially in the 2020–2025 range. This reflects the increasing awareness of researchers on the importance of integrating higher-level thinking skills in science education. Geographically, the articles studied came from various countries with a predominance of research from Turkey, Indonesia, the United States, and Germany. These countries are known to be active in the development of STEM education and pedagogical innovation.

In terms of education, the majority of studies were conducted at the junior high and high school levels, and some at the university level in the context of training prospective science teachers (pre-service teachers). This shows that argumentation skills are starting to gain attention not only as part of student learning, but also as a pedagogical competence that future teachers need to have. The flow chart of the results of the article selection can be seen in the developed Chart 1. from Watase Uake Tools, based on Prisma 2020 Reporting



Gambar 1. Bagan alur Tabel Data hasil seleksi artikel

The selected articles were then reviewed in depth based on the criteria that had been set, as shown in **Table 1.**

Tabel 1. Tabel Data Sintesis Artikel SLR

No	Author (Year)	Title	STEM Strategy	Media/ Intervention	Argument Related Result
1	Kruit et al. (2024)	Enhancing students' argumentation skills, content knowledge, and Nature of Science understanding through a web-based educational instrument in the context of socio-scientific issues	Socioscientific Issues (SSI)	Web-based tool	Improved quality of arguments and understanding of Nature of Science (NOS)
2	Şahin Kalyon & Yılmaz (2025)	The Development of Pre-service Primary Teachers' Understanding and Skills of Argumentation through Argument Driven Inquiry	Argument-Driven Inquiry	Guided experiments	The structure of the argument is improved, the scientific justification is stronger
3	Smit et al. (2025)	Using the socioscientific issue approach to foster secondary students' argumentation skills, science self-efficacy beliefs and science interest	Socioscientific Issues	Issue-based discussions	Increases interest in science, self-efficacy, and depth of argument
4	Demircioglu et al. (2023)	The use of online scaffolding to develop argumentation skills	Science Inquiry	Augmented Reality	Significant increase in critical thinking and complex arguments
5	Putra et al. (2023)	Argumentation Tools Based on the Engineering Design Process to Improve Students' Argumentation Skills	Engineering Design Process	Worksheets + design tools	Strengthening argument structure and problem solving through engineering processes
6	Hasnunidah et al. (2023)	Students' Argumentation Skills towards Using Biology e-Worksheet based on ProjectArgumentative Learning Model	Project-Based STEM	E-Worksheet	Help students build and assess arguments in the context of a science project
7	Ucar-Longford et al. (2024)	The use of online scaffolding to develop argumentation skills (Scoping Review)	Mixed	Scaffolding online	Identifying effective scaffolding elements for argumentative learning
8	Vogel et al. (2022)	Adaptable scaffolding of mathematical argumentation skills: The role of self-regulation when scaffolded with CSCL scripts and heuristic worked examples	Mathematical STEM	Heuristic + CSCL script	Adaptive scaffolding support + self-regulation is important in argument formation
9	Kim et al. (2022)	Influence of Scaffolding on Information Literacy and Argumentation Skills in Virtual Field Trips and Problem-Based Learning for Scientific Problem Solving	Problem-Based Learning	Virtual Field Trips + scaffolding	Information literacy and arguments are significantly improved through virtual learning experiences

No	Author (Year)	Title	STEM Strategy	Media/ Intervention	Argument Related Result
10	Jumadi et al. (2021)	PBL + Argument Mapping + Online Lab	PBL-STEM	Argument mapping + lab virtual	Improve the argumentation skills of junior high school students explicitly
11	Canoz et al. (2022)	Infusing Explicit Argumentation in Science Reading Activities: Helping Prospective Science Teachers Reduce Misconception and Foster Argumentation Skills	Science Inquiry	Simulasi interaktif	Increased argumentation, academic achievement, and entrepreneurial spirit of students
12	Lieber et al. (2022)	Students' individual needs matter: A training to adaptively address students' argumentation skills in organic chemistry	Chemistry-based STEM	Adaptive training	Tailor learning to support individual needs in building arguments
13	Taş et al. (2022)	The impact of the argumentation-flipped learning model on the achievements and scientific process skills of students	Flipped Learning + STEM	Video + diskusi argumentatif	Improve students' scientific process skills and academic achievement
14	Su et al. (2022)	The impact of thinking tools on the argumentation skills of pre-service science teachers in flipped learning	Flipped STEM	Thinking tools	Improved pre-service teacher arguments in online environments
15	Aldahmash & Omar (2021)	Analysis of activities included in Saudi Arabian chemistry textbooks for the inclusion of argumentation-driven inquiry skills	STEM (analisis kurikulum)	ADI-based activities in books	Identification of low explicit integration of arguments in textbooks
16	Larrain et al. (2021)	Argumentation skills mediate the effect of peer argumentation on content knowledge in middle-school students	Collaborative Argumentation	Peer discussion	Argumentation is an important mediation in understanding science content
17	Homburger et al. (2021)	Building argumentation skills in the biology classroom: an evolution unit that develops students' capacity to construct arguments from evidence	Argument-Driven Inquiry	Evolutionary units	Students can develop evidence-based arguments in biological contexts
18	Belland & Kim (2021)	Predicting high school students' argumentation skill using information literacy and trace data	STEM + literasi informasi	Trace data analysis	Information literacy plays an important role in the quality of students' arguments
19	Jumadi et al. (2021)	The Impact of Problem-Based Learning with Argument Mapping and Online Laboratory on Scientific Argumentation Skill	PBL-STEM	Argument map + online lab	Improving the quality of arguments and scientific attitudes of junior high school students
20	Uzuntiryaki-Kondakci et al.	The role of the argumentation-based laboratory on the development of pre-service	Argumentation Lab	Argument-based practicum	Improve the ability to construct and evaluate complex arguments

No	Author (Year)	Title	STEM Strategy	Media/ Intervention	Argument Related Result
		chemistry teachers' argumentation skills			
21	Hosbein et al. (2021)	Tracking student argumentation skills across general chemistry through argument-driven inquiry using the assessment of scientific argumentation in the classroom observation protocol	Argument-Driven Inquiry	ASAC Observation Protocol	Consistent improvement throughout the semester through observation-based assessments
22	Indrawati ningsih et al. (2020)	*Argument mapping to improve student's mathematical argumentation skills*	Math-STEM	Argument map	Mathematical argument capabilities are improved through argument mapping
23	Chen et al. (2020)	Effects of multi-genre digital game-based instruction on students' conceptual understanding, argumentation skills, and learning experiences.	Game-based STEM	Multi-genre game digital	Reinforcing science concepts and the ability to argue in a fun way
24	Ping et al. (2020)	Explicit Teaching of Scientific Argumentation as an Approach in Developing Argumentation Skills, Science Process Skills and Biology Understanding	Explicit Instruction STEM	Explicit Argumentation + Experiment Model	Improved argumentation, understanding of biology, and science process skills
25	Akhdinir wanto et al. (2020)	Problem-based learning with argumentation as a hypothetical model to increase the critical thinking skills for junior high school students	PBL + Argumentation	Exploratory group activities	Students' argumentation and critical thinking increase in junior high school
26	Montaño & Padilla (2020)	Teaching argumentation skill in chemistry high school courses	Chemistry STEM	Simulation of experiments and scientific debates	Help students develop logic and data-driven arguments
27	Uçar & Demirasl an (2020)	The effect of argument mapping supported with peer feedback on pre-service teachers' argumentation skills	Peer-assisted Argumentation	Argument map + friend feedback	Student arguments are more complex and structured
28	Song & Sparks (2019)	Measuring argumentation skills through a game-enhanced scenario-based assessment	STEM + Assessment	Game skenario	Measuring and developing arguments with innovative media
29	Gülen & Yaman (2019)	*The effect of ıntegration of STEM disciplines into toulmin's argumentation model on students' academic chievement, reflective thinking, and Psychomotor Skills*	STEM-Toulmin Integration	Projects + experiments	Improve reflective, academic, and psychomotor skills
30	Hsu et al. (2018)	Argue like a scientist with technology: the effect of within-gender versus cross-gender team argumentation	Technology-enhanced STEM	Gender-based collaboration	Argumentative collaboration improves knowledge and social skills

No	Author (Year)	Title	STEM Strategy	Media/ Intervention	Argument Related Result
		on science knowledge and argumentation skills among middle-level students			
31	Si et al. (2019)	Developing clinical reasoning skills through argumentation with the concept map method in medical problem-based learning	PBL + STEM	Concept map and clinical debate	Improve reasoning skills and formulate clinical arguments in medical education
32	Lin et al. (2018)	The effects of computerized inquiry-stage-dependent argumentation assistance on elementary students' science process and argument construction skills	Inquiry STEM	Computer-assisted scaffolding	Step-by-step improvement of argument construction and scientific process
33	Dawson & Carson (2017)	Using climate change scenarios to assess high school students' argumentation skills	SSI-STEM	Climate change scheme	Improving the quality of argument structure in high school with the context of global issues
34	Hsu et al. (2016)	A cross-cultural study of the effect of a graph-oriented computer-assisted project-based learning environment on middle school students' science knowledge and argumentation skills	Computer-PBL-STEM	Interactive digital graphics	Have a positive influence on the argument structure of junior high school students across cultures
35	Vogel et al. (2016)	Developing argumentation skills in mathematics through computer-supported collaborative learning: The role of transactivity	CSCL-STEM	Online collaboration	Transactivity is important in increasing the depth of mathematical arguments
36	Karpudewan et al. (2016)	The role of green chemistry activities in fostering secondary school students' understanding of acid–base concepts and argumentation skills	Environmental STEM	Environment-based practicum	Improved understanding of chemistry concepts and argumentation skills
37	Hsu et al. (2015)	Enhancing skill in constructing scientific explanations using a structured argumentation scaffold in scientific inquiry	Inquiry STEM	Scaffold digital	Improve the ability to compose scientific explanations with argument structures
38	Hsu et al. (2015)	The effect of a graph-oriented computer-assisted project-based learning environment on argumentation skills	PBL-STEM	Digital graphics	Significant increase in knowledge and argumentation
39	Demiral & Çepni (2018)	Examining argumentation skills of preservice science teachers in terms of their critical thinking and content knowledge levels: An example using GMOs	Science-based arguments (GMOs)	Controversial issues about GMOs, critical thinking tests,	Argumentation skills are influenced by the level of knowledge and critical thinking. Students with high CT produce stronger arguments

No	Author (Year)	Title	STEM Strategy	Media/ Intervention	Argument Related Result
				argumentation rubrics	
40	Ajani & Matiyenga (2025)	Enhancing Critical Analysis and Argumentation Skills in University Students Through Multimodal Approaches	Multimodal-based Instruction	visual, verbal, and digital media; Multimodal Presentation	Multimodal approach improves the ability to analyze arguments and build arguments across formats (text, images, audio)

The results of the review show that the dominant learning approaches used to improve argumentation skills in the STEM context include Argument-Driven Inquiry (ADI), Project-Based Learning (PjBL), Socioscientific Issues (SSI), and Engineering Design Process (EDP). ADI is widely used because it integrates scientific practice, guided inquiry, and argumentative report writing. Studies such as Şahin Kalyon & Yılmaz (2025) and Uzuntiryaki-Kondakci et al. (2021) show that ADI is effective in systematically shaping the structure of students' arguments. PjBL-STEM emphasizes collaboration in real-world project completion and provides space for students to formulate arguments to defend their designs. SSI-STEM emphasizes more on data-driven decision-making in controversial issues with social and ethical dimensions, which is very relevant for the development of reflective and argumentative thinking skills. The results of the comparison of approaches, the focus of the argument, and the media used can be seen in table 2 for a concise and easy-to-read view.

STEM STRATEGY	FOCUS OF ARGUMENT	MEDIA DOMINAN
ADI	Structure & justification of arguments	Experiments, observation protocols
SSI	Value-based arguments and scientific evidence	Web-based tools, open discussions
PBL	Problem-based solutions & arguments	VFT, lab virtual, mapping
Flipped	Reflection on arguments through class discussions	Video, LMS, thinking tools
EDP	Arguments in technical design	Worksheet EDP, prototipe
Teknologi Scaffolding	Adaptive support for structuring & evaluating arguments	CSCL, scaffolding online, peer FB

The media used in learning interventions are very diverse, reflecting innovative and adaptive learning tendencies. STEM-based LKPD has been widely developed, for example in the form of an e-worksheet (Hasnunidah et al., 2023) which presents project-based challenges accompanied by scaffolding to formulate arguments. Technology-based media such as digital simulation, robotics, and coding are used to amplify immersive contextual experiences and support experimental data-driven arguments.

In addition, many studies apply the Toulmin model as a basis to guide students in constructing arguments (claim–data–warrant). Some interventions use explicit scaffolding, argument mapping, and dialogic teaching to improve the quality of students' debate and exploration of scientific ideas.

The assessment of argumentation skills in the article studied is carried out through various approaches. The Toulmin model is the most dominant approach, used as both a learning tool and an assessment. The Toulmin Argument Pattern (TAP) assesses the structure of students' arguments in terms of claims, evidence, reasoning, backing, and rebuttals.

Beberapa artikel menggunakan rubrik penilaian argumentatif yang telah divalidasi, seperti ASAC (Assessment of Scientific Argumentation in the Classroom) Protocol. Penilaian dilakukan baik secara formatif (melalui observasi dan umpan balik dalam diskusi) maupun sumatif (melalui laporan tertulis atau presentasi argumen proyek). Adanya variasi teknik asesmen mencerminkan pentingnya keterpaduan antara instruksi dan evaluasi dalam membentuk argumentasi ilmiah siswa.

Based on the synthesis of the article, the majority of intervened STEM approaches showed effectiveness in improving students' argumentation skills, especially in terms of crafting valid claims, linking data to logical reasons, and delivering meaningful rebuttals. Interventions with explicit approaches such as ADI and SSI showed stronger results than implicit approaches.

The types of research designs used include quasi-experiments, descriptive qualitative studies, and mixed method approaches. Quasi-experimental studies dominate, generally involving experimental and control groups

as well as measurements of pre-post argumentation skills. Qualitative studies also make an important contribution in describing the learning process and the dynamics of student argumentation in depth.

Some of the interesting findings from the study include the application of artificial intelligence-based technology to detect and provide automatic feedback on argument structures, as well as the use of interactive game-based learning media. Nonetheless, there are a number of research gaps identified.

First, there is still little research evaluating the long-term impact of argumentative interventions in STEM. Second, most approaches have not explicitly designed assessments that are adaptive to the argumentative abilities of students with diverse backgrounds. Third, implementation limitations often arise in the form of inadequate learning time, low teacher readiness, and lack of training in applying argumentative approaches.

Recommendations for the future include the need to develop more explicit STEM learning models in integrating scientific argumentation, teacher training in the use of rubrics and scaffolding arguments, and the exploration of interactive digital media based on local contexts and global challenges

4. CONCLUSION

Based on the results of a systematic review of 40 scientific articles that examined the development of argumentation skills in STEM-based learning, it can be concluded that the explicit integration of STEM approaches has proven to be effective in improving the quality of students' scientific argumentation. These findings answer a key question in the study, namely that certain learning approaches and media, such as Argument-Driven Inquiry (ADI), Project-Based Learning (PjBL), Socioscientific Issues (SSI), and Engineering Design Process (EDP), are strategies that are consistently used to encourage students' ability to structure claims, evidence, and reasons in a structured manner.

Learning media such as STEM-based LKPD, digital simulation, argument mapping, and technology-based scaffolding have also been proven to contribute to supporting students' critical and argumentative thinking processes. The assessment of argumentative skills is most often carried out with the Toulmin model approach and argumentative rubrics designed according to the structure of scientific arguments.

However, gaps are still found in the literature related to the limitations of argumentative intervention designs that are fully integrated in STEM learning. In addition, there is still a lack of longitudinal studies that evaluate the long-term impact on the development of students' arguments.

Based on these findings, it is recommended that further research develop a STEM learning model that explicitly integrates strategies to strengthen scientific arguments, complemented by adaptive assessments. Teachers and curriculum developers are also advised to make optimal and contextual use of technology-based media to be able to accommodate the learning needs of students in the 21st century.

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