The Power of Argumentation: A Systematic Literature Review on Science Learning and Multiple Skills Development

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https://doi.org/10.24191/ajue.v21i3.55

Received: 7 March 2025
Accepted: 13 July 2025
Date Published Online: 31 October 2025
Published: 31 October 2025

Abstract: Argumentation plays a crucial role in science learning, enhancing students' critical thinking, conceptual understanding, and metacognitive skills. This study examines research trends on argumentation in science education by analyzing 41 Scopus-indexed journal articles published between 2020 and 2025. The findings indicate a significant increase in research interest, particularly since 2023, with Indonesia (36.6%) and Turkey (34.1%) being the most active contributors. Various argumentation-based approaches have been developed, including Argumentation-Driven Inquiry (ADI), Toulmin's Argumentation Pattern, Argumentation-Promoted Interactive Simulation, and Dialogical Argumentation, each demonstrating positive impacts on students' academic achievement, argumentation skills, and science literacy. Most studies employed quantitative methods, with quasi-experimental designs being the most prevalent (36.6%). Mixed-method research and design-based research (DBR) approaches were also utilized to provide deeper insights into the implementation of argumentation in science education. Participants in these studies were predominantly students (56.1%), followed by pre-service teachers (31.7%), reflecting the growing emphasis on preparing future educators in argumentation-based pedagogy. The study highlights the importance of integrating argumentation into science curricula to enhance critical thinking and problem-solving skills. It is recommended that future research expand to underrepresented regions and explore the long-term effects of argumentation-based learning. Additionally, professional development programs should be strengthened to equip educators with effective strategies for implementing argumentation in the classroom. These findings underscore the global relevance of argumentation in science education and its potential to foster scientifically literate and critically minded individuals.

Keywords: Multiple Skills Development, Power of Argumentation, Systematic Literature Review, Science Learning

1. Introduction

The growing complexity of the modern world has led to a strong emphasis on developing 21st-century skills. This focus is driven by three main factors: the global shift from a manufacturing-based economy to one that prioritizes information, knowledge, and innovation; the increasing demand for new job-related competencies; and the pressing need to bridge the skills gap among learners (Evans et al., 2020; Sihombing et al., 2025). Originating in the United States, this movement has since influenced many countries, including Singapore, Hong Kong, and Australia. In 21st-century education, both teachers and students are seen as co-learners who actively engage in the learning process. The Partnership for 21st Century Learning Framework emphasizes essential competencies, including critical thinking, problem-solving, communication, collaboration, creativity, innovation, technology literacy, contextual learning, and information and media literacy (BSNP, 2010). These skills are grouped into four overarching categories: (1) ways of thinking, (2) ways of working, (3) tools for working, and (4) living in the world (Binkley et al., 2012; Evans, 2020; Saleem et al., 2024).

In Indonesia, 21st-century skills are integrated into the *Merdeka Kurikulum*, with competencies that include critical, creative, independent, collaborative, communicative, and solution-oriented thinking. The learning principles outlined in the *Merdeka Kurikulum* include a shift from content-based learning to competence-based learning, the enhancement of both physical and mental skills, and the use of technology to improve learning efficiency (Hunaepi & Suharta, 2024; Saa, 2024). These skill elements align with the development of 21st-century skills.

Argumentation is the process used to strengthen a claim or opinion through critical thinking analysis supported by logical evidence and acceptable reasons. These pieces of evidence can be facts or objective conditions accepted as truth (Murdani et al., 2023; Muslim et al., 2024; Rosmiati et al., 2024). In Toulmin's Argumentation Pattern (TAP), scientific argumentation consists of several main components: data, claim, warrant, backing, and rebuttal. Data refers to the phenomena or evidence used to support the claim being made. A claim is a statement or opinion based on existing values or a perspective taken on a situation. The warrant explains the relationship between the data and the claim, providing the basis for why the claim is acceptable. Backing is the foundational assumption underlying the warrant, while rebuttal encompasses conditions where the claim cannot be proven or opposing arguments need to be considered (Chen et al., 2024; Topalsan et al., 2020; Walid et al., 2023).

Scientific argumentation skills are crucial to develop in science education, particularly for enabling students to think logically and critically. With strong argumentation skills, students can provide clear and rational explanations of the material being studied and explain phenomena in everyday life based on relevant scientific concepts or theories (Hendratmoko et al., 2024; Osborne et al., 2012; Palma-Jiménez et al., 2023; Yıldız-Feyzioğlu & Kiran, 2021). Argumentation plays a vital role in educational research as it helps students develop critical thinking and evidence-based reasoning skills (Tang & Putra, 2025). In argumentation-based science education, students present evidence, data, and valid theories to support their claims about a problem or phenomenon being studied (Anisa et al., 2023; Nasir & Kusumadani, 2024; Misbah et al., 2023; Robertshaw & Campbell, 2013). This process not only encourages active student involvement in thinking and discussing, but also helps them hone the analytical thinking skills essential in the real world.

Despite its importance, students' argumentation skills remain relatively low, indicating that there is still considerable room for improvement in education (Huang et al., 2025; Lestari et al., 2024a; Muslim et al., 2024). Students' argumentation skills can be enhanced over time through a learning process that involves evidence-based discussions and reinforcement of science concepts (Archila et al., 2023; Kalyon & Yilmaz, 2023; Perdana et al., 2024). Therefore, research focused on improving argumentation skills is essential. Additionally, students' literacy skills, which include understanding and using relevant information in scientific contexts, have a significant impact on their argumentation abilities. The higher the scientific literacy of students, the more likely they are to present strong, evidence-based arguments. Scientific literacy, encompassing fields such as science, plays a crucial role in the advancement of science and technology (Lestari et al., 2024b). Therefore, it is important to conduct research that integrates argumentation into learning, as it can enhance various student skills, especially 21st-century skills, including critical thinking, communication, collaboration, and creativity.

However, despite various valuable studies, there has been no systematic literature review focusing on the implementation of argumentation in science learning to develop multiple skills. While several individual studies have explored how argumentation is integrated into science education, a comprehensive synthesis of its contributions to the development of multiple skills across different educational contexts is still lacking. A systematic literature review (SLR) is needed to provide deeper insights into both the effectiveness and the challenges of incorporating argumentation into science learning. This study not only offers a broad overview of the role of argumentation and its impact on skill development but also introduces a more structured and transparent research approach through the use of SLR. Such an approach enables future research to build on more reliable and replicable foundations. The integration of argumentation with other instructional strategies is essential for educators and practitioners, as it can bridge various skill domains in science education. Therefore, this study seeks to answer several key questions:

(1) What have previous studies reported about the implementation of argumentation in science learning to foster multiple skills?
(2) How is research on argumentation in science learning distributed by publication year concerning skill development?
(3) What research designs are most commonly used on argumentation in science learning?
(4) Which educational levels has argumentation in science learning been most frequently studied?
(5) Which countries have researched argumentation in science learning?

2. Research Methods

A. Research Design

A Systematic Literature Review (SLR) is a structured and thorough evaluation of a specific research area, conducted by experts in the field. According to Xiao and Watson (2019), an SLR follows a systematic approach with predefined criteria to identify, analyze, and synthesize relevant studies, providing a comprehensive overview of existing knowledge on a particular topic. This method enables researchers to critically assess gaps in theories, research methodologies, and empirical findings while identifying potential directions for future studies. By systematically examining the components, strengths, and limitations of the subject, researchers can offer an insightful and well-founded interpretation. As highlighted by Cottrell (2017) and Wallace & Wray (2016), the primary goal is to contribute to the advancement of knowledge by presenting a balanced and informed perspective. The use of this method is particularly relevant in exploring ethnoscience, as it facilitates a detailed investigation of its role in promoting environmental awareness and improving science education.

This study adopted a systematic literature review approach, applying widely accepted methodologies for this type of research. The primary objective was to review the existing body of knowledge on a specific subject and identify potential avenues for future research. Rather than conducting an exhaustive search, performing a retrospective analysis, or defining best practices, the study emphasized a critical evaluation of gaps within existing theoretical frameworks, research methods, and conceptual or empirical findings. Through systematic and content analysis techniques, the researchers reviewed scientific articles published between 2020 and 2025, focusing on topics related to argumentation in science learning and its role in fostering the development of multiple skills.

B. Source of Articles

The study analyzed 41 articles on argumentation in science learning, published between 2020 and 2025. These articles were retrieved from the SCOPUS database using Boolean keyword combinations such as “argumentation” AND “science learning”. The selection process involved several stages, including title screening, abstract and full-text review, and the application of inclusion criteria focusing on empirical, peer-reviewed studies relevant to science education.

C. Data Collections Process

The review process involved several key stages:

1. Data Selection: This stage involved defining research questions and identifying relevant articles for the study. Inclusion criteria, as detailed in Table 1, were established to guide the selection process. Articles were sourced from the SCOPUS database using Publish or Perish software. Researchers refined the selection based on these criteria, ultimately analyzing 41 articles. The review process began with an initial assessment of abstracts, followed by an in-depth examination of the full content of the selected articles.

Table 1

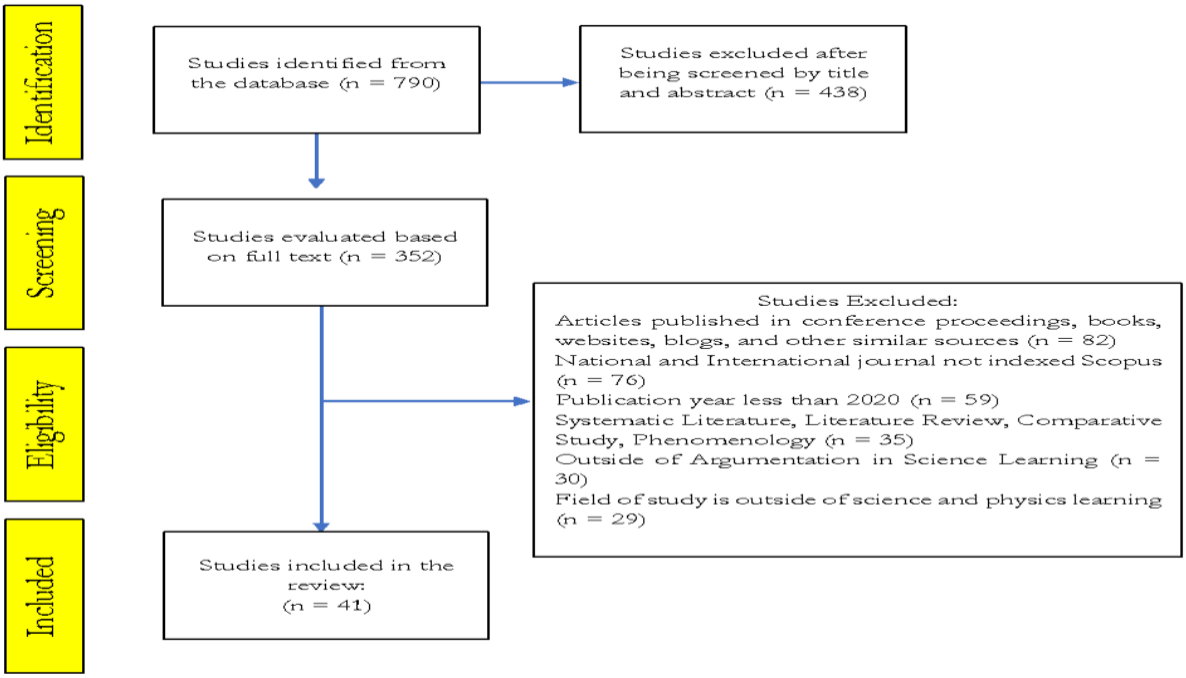
Inclusion and Exclusion Criteria

No.	Category	Inclusion Criteria	Exclusion Criteria
1.	Type of Publication	Articles published in journals	Articles published in conference proceedings, books, websites, blogs, and other similar sources
2.	Journal Specifications	Scopus minimally indexes the international journal	National or International journal not indexed by Scopus
3.	Publication Year	2020 - 2025	Less than 2020
4.	Research Setting	Qualitative, Quantitative, Mixed Methods, Research and Development, and Design-Based Research	Systematic Literature, Literature Review, Comparative Study, Phenomenology
5.	Independent Variable	Argumentation in Science Learning	Outside of Argumentation in Science Learning
6.	Field	Science Education and Physics Education	Outside of science education and physics education

2. Coding Instrument Adaptation: The researchers utilized the Paper Classification Form (PCF), a framework developed by Kizilaslan et al. (2012), as the basis for their coding process. Recognized for its reliability and validity, the PCF encompasses various indicators, including the title, author details, journal information, publication year, journal type, language, indexing, primary discipline, research methodologies, data collection techniques, sample characteristics, and data analysis methods. Additionally, the researchers created a data matrix to document information on research objectives, integrated learning models, thematic aspects, and key findings. The collected data was then analysed using percentage-based calculations.
3. Identifying Article Patterns: The researchers aimed to identify patterns within the analysed articles, focusing specifically on findings related to argumentation in science learning and skill development through the use of the argumentation method. These patterns were systematically synthesized to address the research questions posed in the study.
4. Synthesizing Patterns to Address Research Questions: The synthesis process involved integrating and analyzing the identified patterns to address the research questions outlined in the study comprehensively. This stage focused on consolidating findings from the selected articles to provide well-rounded responses to the research inquiries, as illustrated in Figure 1.

Figure 1

Flowchart of the Article Selection Procedure



The journals used in the articles, along with information regarding indexing and accreditation, are presented in Table 2.

Table 2

The Shortlisted Articles for Review

No	Name of Journal	f	(%)	Indexed/Accredited By
1.	Science and Education	10	24.4	Scopus (Q1)
2.	Jurnal Penelitian Pendidikan IPA (JPII)	3	7.3	Scopus (Q3)
3.	Participatory Educational Research (PER)	2	4.9	Scopus (Q2)
4.	Reflective Practice	2	4.9	Scopus (Q1)
5.	TEM Journal	2	4.9	Scopus (Q3)
6.	Thinking Skills and Creativity	2	4.9	Scopus (Q1)
7.	African Journal of Research in Mathematics, Science and Technology Education	1	2.4	Scopus (Q2)
8.	Cakrawala Pendidikan	1	2.4	Scopus (Q3)
9.	Computers and Education	1	2.4	Scopus (Q1)
10.	Eurasian Journal of Educational Research	1	2.4	Scopus (Q3)
11.	Heliyon	1	2.4	Scopus (Q3)
12.	International Journal of Education and Practice	1	2.4	Scopus (Q3)
13.	International Journal of Evaluation and Research in Education (IJERE)	1	2.4	Scopus (Q3)
14.	International Journal of Science and Mathematics Education	1	2.4	Scopus (Q1)
15.	International Journal of Science Education	1	2.4	Scopus (Q1)
16.	Journal of Baltic Science Education	1	2.4	Scopus (Q2)
17.	Journal of Digital Learning in Teacher Education	1	2.4	Scopus (Q1)
18.	Journal of Education and Learning (EduLearn)	1	2.4	Scopus (Q3)

No	Name of Journal	f	(%)	Indexed/Accredited By
19.	Journal of Educational Psychology	1	2.4	Scopus (Q1)
20.	Journal of Engineering Science and Technology	1	2.4	Scopus (Q3)
21.	Journal of Materials Education	1	2.4	Scopus (Q4)
22.	Journal of Research on Technology in Education	1	2.4	Scopus (Q1)
23.	Journal of Science Education and Technology	1	2.4	Scopus (Q1)
24.	Journal of Science Teacher Education	1	2.4	Scopus (Q1)
25.	Journal of Turkish Science Education	1	2.4	Scopus (Q2)
26.	Teaching and Teacher Education	1	2.4	Scopus (Q1)
	Total	**41**	**100**	

3. Results and Discussions

RQ1: What have previous studies reported about the implementation of argumentation in science learning to foster multiple skills?

This systematic literature review analyzes articles published between 2020 and 2025, with a focus on studies that conduct research on argumentation in science learning. The findings from 41 articles are presented in Table 3.

Table 3

Distribution of Research Based on Previous Study Results

Model	Skill/Purpose	Authors	Results
Argumentation-Driven Inquiry (ADI)	Achievement, science process, and argumentation skills	Arslan et al. (2023)	The ADI model improved PSTs' skills, content understanding, and learning retention, while also gaining their positive response toward its use.
	Understanding and Skills of Argumentation	Kalyon & Yilmaz (2023)	PPTs' understanding of argumentation significantly improved based on their AT responses.
	Creative thinking skills	Ramdani et al. (2021)	The findings indicate that the open inquiry class achieved a significantly higher average score compared to the other two classes.
	Scientific thinking skills and conceptualizing of the 'matter' subject	Bag & Calik (2022)	The game was piloted with 12 fourth-grade students using a design-based research approach.
	Perspectives on teaching science	Alfarraj et al. (2023)	The findings showed that science teachers used ADI less often than anticipated.
	Argumentation Performance	Su et al. (2024)	In a BSLE setting, the ADI approach improved primary students' argumentation skills in both rural and urban schools.

Model	Skill/Purpose	Authors	Results
	Science Content Achievement, Metacognition and Epistemological Beliefs	Deprem et al. (2023)	The treatment group outperformed the comparison group in science mastery, metacognition, and epistemological beliefs.
	Nature of Scientific Inquiry	Erenler et al. (2024)	Pre-service teachers improved across all NOSI aspects, especially in understanding scientific methods and distinguishing data from evidence.
	Scientific argumentation ability	Lestari et al. (2024a)	The IB-NOSA model is effective for improving scientific argumentation in lower secondary science learning.
	Scientific literacy skills	Lestari et al. (2024b)	All groups showed significant gains in scientific literacy, with the highest effect from the IB-NOSA model.
Argumentation Pattern (Toulmin, Assessment, and Map)	Reflective thinking	Rosmiati et al. (2024)	Ocean climate lectures using prediction-argumentation effectively enhance pre-service teachers' reflective thinking.
	Critical Thinking	Chen et al. (2024)	Students' critical thinking improved gradually, following three key processing patterns: Recognise – Understand, Evaluate – Recognise, and Create – Understand.
	Students' Understanding of Factual, Conceptual, Procedural, and Metacognitive Knowledge	Walid et al. (2023)	The study developed a validated argumentation test matrix supported by content analysis and learning tools.
	Scientific inquiry skills	Topalsan (2020)	A statistically moderate effect was found in teachers' posttest scores on the Virtual Lab Opinion Scale and the Scientific Inquiry Principles scale.
	Argumentation Skills	Muslim et al. (2024)	The AG model with Toulmin's pattern effectively improves students' argumentation skills in physics.
	Scientific argumentation skill	Perdana et al. (2020)	The findings suggest that the test is capable of assessing and distinguishing students' scientific argumentation skills at varying levels within the school.

Model	Skill/Purpose	Authors	Results
	Critical Thinking	Giri & Paily (2020)	The TAP–TRGSR approach enhanced students' critical thinking more effectively than traditional methods.
	Self-efficacy for Argumentation and Critical Thinking Skills	Yıldız-Feyzioğlu & Kiran (2021)	Students' effort and confidence in argumentation positively predicted the quality and clarity of their arguments.
	Argumentation Competencies	Altun & Ozsevgec (2025)	Pre-service science teachers enhanced their written and oral argumentation skills, using and adapting various argumentation schemes.
Argumentation-Promoted Interactive Simulation (AR-based and computer-based)	Argumentation levels, academic achievements, and entrepreneurship skills	Canoz et al. (2022)	The study found significant gains in achievement, entrepreneurship, and argument formation, but not in objection skills.
	Students' Critical Thinking Skills and Argumentation Abilities	Demircioglu et al. (2023)	Critical thinking improved early in the intervention, then showed varied use afterward.
	Increase Concept Mastery and Argumentation Skills	Murdani et al. (2023)	The PABCSCHL model improves concept mastery and argumentation skills, and is suitable for hybrid learning on socio-scientific issues.
Dialogical Argumentation	Conceptual Mathematical Problems in Physics	Iwuanyanwu & Ogunniyi (2020)	DAIM was more effective than TTM in enhancing pre-service teachers' problem-solving and argumentation skills.
	Conceptual Change	Li et al. (2023)	Collaborative argumentation caused delayed but lasting conceptual change in science learning.
Argumentation scaffolding and mental rotation	Pupils' computational thinking and reducing their cognitive load	Wang et al. (2024)	Argumentation scaffolding improved critical thinking and eased cognitive load; mental rotation affected only critical thinking.
	Argumentation skills	Ucar-Longford et al. (2024)	Holistic online scaffolding in teacher education effectively strengthens pre-service teachers' argumentation skills.
Metacognitive Argument-Driven Inquiry (MADI)	Conceptual Understanding and Argumentation Skills	Antonio et al. (2021)	The MADI approach greatly enhanced students' understanding and argumentation skills.
Drama	Argumentation Skills	Archila et al. (2023)	The sequence improved participants' GM food argumentation by strengthening viewpoints and counterargument awareness.

Model	Skill/Purpose	Authors	Results
Prediction-Argumentation	Reflective thinking	Rosmiati et al. (2020)	Structured worksheets support students' argumentation and effectively enhance the reflective thinking skills of pre-service physics teachers.
Idiom-Driven Learning	Low achievers' science comprehension, motivation, and argumentation	Lin (2023)	The web-based idiom strategy boosted students' science motivation, understanding, and argumentation through culturally familiar expressions.
Rebuttal Analysis Framework	Argumentation skills	Anisa et al. (2023)	The framework clarified classroom argumentation, but argumentation-based lessons didn't always boost students' skills.
Instruction Based on a Validated Learning Progression	Argumentation Competence	Palma-Jiménez et al. (2023)	The experimental group improved in all learning aspects except counter-critiquing.
Epistemologically enriched argumentation instruction	Academic Achievement	Kızkapan & Bektas (2021)	Students in the experimental groups performed better than the comparison group, with results discussed and recommendations provided.
Argumentation-driven inquiry laboratory (ADIL)	Critical Thinking and Problem Solving	Misbah et al. (2024)	The e-module enhances critical thinking and understanding of fluid dynamics, and is recommended for further limited trials.
Argumentation-Flipped Learning (AFL) Model	Achievements and Scientific Process Skills	Tas et al. (2022)	Instructional methods had no significant impact on students' scientific skills or academic performance.
Debate based on inquiry learning	Argumentation Skills	Hendratmoko et al. (2024)	The study confirms that implementing the DBOIL model in learning activities effectively enhances students' scientific argumentation skills.
Commognitive Approach	Argumentation Skills	Lestari et al. (2021)	Prospective teachers' argumentation skills reflect the commognitive framework through narratives, visuals, and language use.
STEM Integrated Argumentation-Based Inquiry Applications	Academic Success, Reflective Thinking, and Creative Thinking Skills	Yesildag-Hasancebi (2021)	Integrating STEM into the ABI approach effectively boosts students' reflection, creativity, and achievement.
Project Argumentative Learning Model	Argumentation Skills	Hasnunidah et al. (2023)	Experimental class students had significantly stronger argumentation skills than the control group.

Model	Skill/Purpose	Authors	Results
Anticipation Guides (AG) in Reading Activities	Scientific Written Arguments	Gumilar et al. (2023)	The AG approach significantly improved students' scientific writing and argument structure.
Peer Argumentation on Content Knowledge	Argumentation Skills Mediate	Larrain et al. (2020)	Peer argumentation boosted students' argument skills and content knowledge, both directly and over time.

Argumentation plays a crucial role in science learning, as it can enhance students' critical thinking skills, conceptual understanding, and metacognitive abilities. Various argumentation-based approaches have been developed to support this achievement. The Argumentation-Driven Inquiry (ADI) approach emphasizes argumentation-based scientific inquiry that contributes to students' academic achievement, science process skills, and argumentation skills (Arslan et al., 2023). Several other studies have shown that ADI also improves understanding and argumentation skills (Kalyon & Yilmaz, 2023), creative thinking skills (Ramdani et al., 2021), as well as scientific thinking and conceptualization of 'material' concepts (Bag & Calik, 2022). In addition, ADI also contributes to the understanding of the nature of scientific inquiry (Erenler et al., 2024) and scientific literacy (Lestari et al., 2024b).

The Argumentation Pattern (Toulmin, Assessment, and Map) approach refers to Toulmin's argumentation patterns, which are utilized in various assessments and argumentation mapping. Studies have shown that this approach can enhance reflective thinking (Rosmiati et al., 2024), critical thinking (Chen et al., 2024), as well as the understanding of factual, conceptual, procedural, and metacognitive knowledge (Walid et al., 2023). In addition, this approach also contributes to scientific inquiry skills (Topalsan, 2020) and argumentation competence (Altun & Ozsevgec, 2025).

The Argumentation-Promoted Interactive Simulation approach, which is based on interactive simulations (both AR and computer-based), improved students' argumentation levels, academic achievement, and entrepreneurial skills (Canoz et al., 2022). In addition, this approach also plays a role in enhancing students' critical thinking and argumentation skills (Demircioglu et al., 2023), as well as improving concept mastery and argumentation skills (Murdani et al., 2023).

The Dialogical Argumentation approach emphasizes dialogical interaction in argumentation to assist students in understanding conceptual problems in mathematical physics (Iwuanyanwu & Ogunniyi, 2020) and to promote conceptual change (Li et al., 2023). Argumentation Scaffolding and Mental Rotation approaches aim to improve students' computational thinking and reduce their cognitive load (Wang et al., 2024), as well as improve argumentation skills (Ucar-Longford et al., 2024). The Metacognitive Argument-Driven Inquiry (MADI) approach integrates argumentation and metacognitive strategies to enhance students' conceptual understanding and argumentation skills (Antonio et al., 2021).

In addition to the main approaches above, there are several other argumentation methods applied in science learning, including Drama, which improves argumentation skills through a role-based approach (Archila et al., 2023), Prediction-Argumentation, which enhances students' reflective thinking (Rosmiati et al., 2020), and Idiom-Driven Learning, which plays a role in improving low-achieving students' science understanding and their motivation (Lin, 2023). The Rebuttal Analysis Framework approach focuses on analysing rebuttals in argumentation (Anisa et al., 2023), while Epistemologically Enriched Argumentation Instruction improves students' academic achievement (Kızkapan & Bektas, 2021). Other approaches, such as the Argumentation-Driven Inquiry Laboratory (ADIL), contribute to improving critical thinking and problem-solving skills (Misbah et al., 2024). Additionally, the Argumentation-Flipped Learning (AFL) Model enhances academic achievement and science process skills (Tas et al., 2022).

The Debate-Based Inquiry Learning approach helps improve students' argumentation skills (Hendratmoko et al., 2024), while the Commognitive Approach contributes to the development of argumentation skills (Lestari et al., 2021). The integration of argumentation in STEM learning, as in STEM Integrated Argumentation-Based Inquiry Applications, improves academic success, reflective thinking, and creative thinking skills (Yesildag-Hasancebi, 2021). Other models, such as the Project Argumentative Learning Model, focus on developing argumentation skills (Hasnunidah et al., 2023),

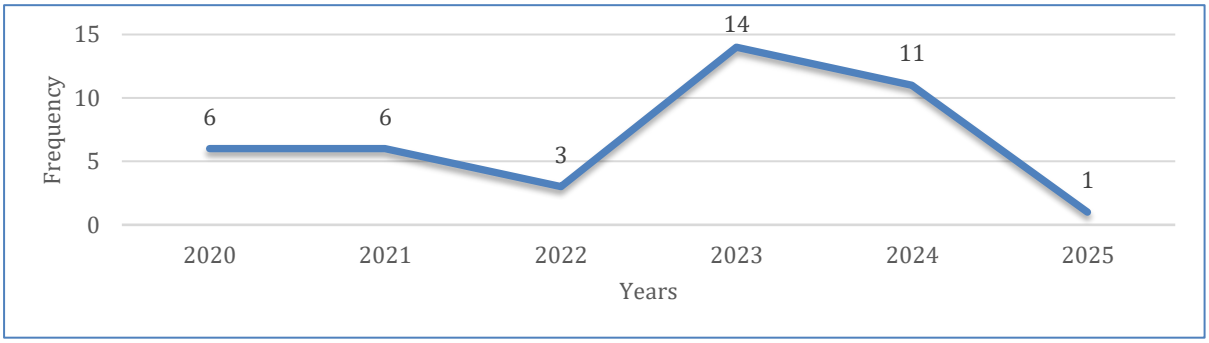
while Anticipation Guides in Reading Activities enhance students' scientific written argumentation (Gumilar et al., 2023). Peer Argumentation on Content Knowledge can also improve argumentation skills mediated by content knowledge (Larrain et al., 2020). Overall, various argumentation-based approaches in science learning offer diverse benefits, ranging from improving critical thinking skills and conceptual understanding to mastering science process skills. Selecting an approach that suits the needs of students and the learning context is crucial for optimizing the expected learning outcomes.

RQ2: How is research on argumentation in science learning distributed by publication year in relation to skill development?

The distribution of the selected research for review spans from 2020 to 2025. The complete data can be seen in Figure 2.

Figure 2

The Distribution of Research Based on the Year of Publication



Based on the distribution of publication years, research on argumentation in science learning has experienced notable fluctuations over the past five years. In 2020 and 2021, six studies were published each year, indicating a relatively consistent foundation. This was followed by a decline in 2022, with only three publications recorded. A significant increase occurred in 2023, reaching a peak of 14 studies, reflecting a heightened research focus on the topic. In 2024, the number slightly declined to 11 publications, while in 2025, a sharp decrease to a single study was observed, likely due to the ongoing nature of the publication cycle. Overall, although interest in argumentation within science education reached its highest point in 2023, the pattern does not reflect a consistent upward trend.

In 2022, the number of publications decreased to 3 studies. This may be due to a change in research trends or a shift in focus to other topics in science education in that year. However, in 2023, there was a significant spike in the number of studies, reaching 14, making it the year with the most publications. This increase reflects the growing interest among academics in the application of argumentation in science learning, particularly in enhancing students' critical thinking skills, science literacy, and academic achievement.

In 2024, the number of studies decreased slightly but remained high, with 11 studies. This suggests that argumentation remains a relevant area of research, with further exploration of innovative methods, such as the use of interactive simulations, debate-based learning, and argumentation approaches, in STEM learning models. For 2025, only one study has been identified so far, which is most likely due to the limited number of publications available for this year. However, given previous trends, it is likely that the number of publications will continue to grow shortly.

Overall, the research trend on argumentation in science learning has shown a significant increase, particularly since 2023. This reflects the importance of argumentation in science education and the growing interest of researchers in developing argumentation-based approaches to improve student learning.

RQ3: How is research on argumentation in science learning distributed by research methods in relation to skill development?

The analysis revealed a variety of research methods used in studies on ethnoscience and its effects on environmental awareness. The trend in the use of research methods is evident in Table 4.

Table 4

The Distribution of Research Based on the Research Methods

Approach	Research Methods	Authors	Frequency	Percentage (%)
Quantitative	Quasi-experiment	Muslim et al. (2024), Su et al. (2024), Lestari et al. (2024a), Wang et al. (2024), Tas et al. (2022), Hasnunidah et al. (2023), Murdani et al. (2023), Palma-Jiménez et al. (2023), Lin (2023), Giri & Paily (2020), Deprem et al. (2023), Walid et al. (2023), Rosmiati et al. (2020), Larrain et al. (2020), Ramdani et al. (2021)	15	36.6
	Correlational study	Yıldız-Feyzioğlu & Kiran (2021)	1	2.4
	True Experimental	Palma-Jiménez et al. (2023)	1	2.4
	One-group pretest-posttest design	Hendratmoko et al. (2024)	1	2.4
Qualitative	Case Study	Demircioglu et al. (2023)	1	2.4
	Interviews	Lestari et al. (2021)	1	2.4
Mixed Method	Exploratory	Ucar-Longford et al. (2024), Alfarraj et al. (2023), Yesildag-Hasancebi (2021)	3	7.3
	Sequential explanatory	Iwuanyanwu & Ogunniyi (2020), Topalsan (2020), Li et al. (2023), Chen et al. (2024), Arslan et al. (2023)	5	12.2
	Embedded	Gumilar et al. (2023), Kalyon & Yilmaz (2023), Altun & Ozsevgec (2025), Rosmiati et al. (2024), Kızkapan & Bektas (2021)	6	14.6
Others	Research and Development	Anisa et al. (2023), Perdana et al. (2020), Lestari et al. (2024b)	3	7.3
	Design-Based Research	Misbah et al. (2024), Erenler et al. (2024), Bag & Calik (2022), Archila et al. (2023)	4	9.8
		Total	**41**	**100**

Research related to argumentation in science learning is dominated by quantitative approaches, particularly with quasi-experimental designs, which were used in 15 studies (36.6%). Some of the studies that used this method were conducted by Muslim et al. (2024), Su et al. (2024), Lestari et al.

(2024a), and Wang et al. (2024). Quasi-experimental methods are widely used to measure the effectiveness of an intervention on students' argumentation skills, critical thinking, and academic achievement. In addition, other quantitative research involved correlational studies (2.4%) by Yıldız-Feyzioğlu & Kiran (2021), actual experiments by Palma-Jiménez et al. (2023) with the same percentage, as well as the one-group pretest-posttest design used by Hendratmoko et al. (2024).

Qualitative approaches were also used, albeit in smaller numbers. The case study method was applied in the study by Demircioglu et al. (2023) with a percentage of 2.4%, while the interview method was used in the research by Lestari et al. (2021) with the same rate. This qualitative research aims to explore students' experiences, their perspectives on argumentation, and the development of argumentation skills in various learning contexts.

The mixed method approach is also widely used, with several variations of methods. An exploratory approach was employed in three studies (7.3%), as seen in works by Ucar-Longford et al. (2024) and Alfarraj et al. (2023). Meanwhile, the sequential explanatory method, which incorporates quantitative analysis at an early stage and is followed by qualitative analysis, was used in five studies (12.2%), including research by Iwuanyanwu & Ogunniyi (2020), Topalsan (2020), and Li et al. (2023). Embedded methods that integrate qualitative data in quantitative research were used in six studies (14.6%), such as those by Gumilar et al. (2023) and Kalyon & Yilmaz (2023).

In addition to quantitative, qualitative, and mixed methods, several studies employed other approaches. Research and development (R&D) was employed in three studies (7.3%) to develop argumentation-based learning tools, as seen in research by Anisa et al. (2023) and Perdana et al. (2020). Meanwhile, the Design-Based Research (DBR) method was applied in four studies (9.8%), including research by Misbah et al. (2024) and Erenler et al. (2024), which aimed to systematically develop and evaluate the implementation of an argumentation-based learning model.

Overall, research on argumentation in science learning shows a strong trend towards quantitative approaches, particularly quasi-experiments, to evaluate the effectiveness of various interventions. However, mixed methods and development research approaches are also widely used to gain a more comprehensive understanding of how argumentation can be applied in science education.

RQ4: Which educational levels has argumentation in science learning been most frequently studied?

This analysis offers insights into the dissemination of previous studies across various educational stages. Detailed data on the distribution of research by educational stage are provided in Table 5.

Table 5

The Distribution of Research Based on the Educational Levels

Participants/Sample	Education Stage (Level)	f	(%)	Total (%)
Student	Elementary/Primary School	7	17.1	56.1
	Junior High School	7	17.1	
	High School	3	7.3	
	University/Undergraduate	6	14.6	
Prospective Teacher	Physics	3	7.3	31.7
	Science	10	24.4	
Other	Science Teacher	3	7.3	12.2
	Lecturer	2	4.9	
Total		**41**	**100**	**100**

Based on the distribution of participants in argumentation research in science learning, the majority of studies involved students as research subjects, totaling 56.1% of all studies. Among the student participants, those from elementary and secondary education levels were the most numerous. A total of 7 studies (17.1%) were conducted on elementary/primary school students, the same number was

also found at the junior high school level, while three studies (7.3%) involved high school students. Studies focusing on university/undergraduate students accounted for six studies (14.6%), suggesting that argumentation in science learning also receives attention at the higher education level.

In addition to students, prospective teachers were also the dominant participants in this study, totalling 31.7%. Of these, physics prospective teachers contributed three studies (7.3%), while science prospective teachers were studied more, with a total of 10 studies (24.4%). This shows that argumentation research in science education focuses not only on students but also on the preparation of future educators.

Other categories of participants included science teachers, with three studies (7.3%), and lecturers, with two studies (4.9%), which together contributed 12.2%. Although the number of studies involving educators is smaller compared to students and prospective teachers, their involvement is still important in understanding how argumentation is applied in teaching practices at different levels of education.

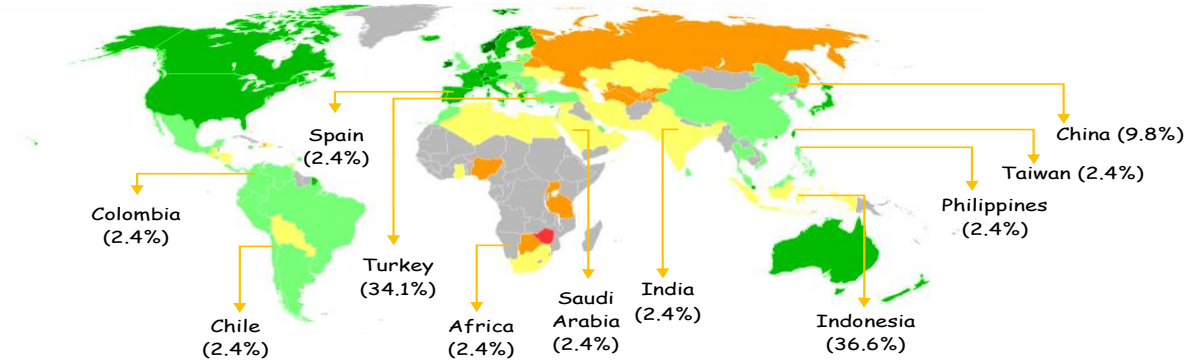
Overall, the distribution of participants in the research on argumentation in science learning indicates that the primary focus is on students, followed by teacher candidates, and a smaller number of teachers and lecturers. This reflects the importance of argumentation in improving science understanding in both learners and educators.

RQ5: Which countries have researched argumentation in science learning?

The Distribution of Research based on the Country of Argumentation in science learning, including the frequency (f) and percentage (%), is presented in Figure 3.

Figure 3

The Distribution of Argumentation in Science Learning Research Based on the Country



Research related to argumentation in science learning has been conducted in various countries, with a primary focus in Indonesia and Turkey. Of the total 41 studies analyzed, Indonesia is the dominant research location, accounting for 15 studies (36.6%). This indicates that argumentation in science learning is a significant concern in the Indonesian educational context, particularly in enhancing critical thinking skills, science literacy, and conceptual understanding among students and prospective teachers.

Turkey took second place with a total of 14 studies (34.1%), reflecting the great interest of Turkish researchers in argumentation-based approaches in science education. This can be attributed to the increasing focus on inquiry- and argumentation-based pedagogy in the Turkish education system.
Several other countries also contributed to this research, albeit in smaller numbers. China contributed four studies (9.8%), followed by South Africa, India, the Philippines, Taiwan, Saudi Arabia, Colombia, and Spain, each with one study (2.4%). These countries demonstrate an interest in the implementation of argumentation in science learning, although the number of studies is still relatively limited compared to those in Indonesia and Turkey.

The presence of studies from various countries shows that the argumentation approach in science learning has received global attention. However, the dominance of research in Indonesia and Turkey indicates that these two countries are more active in exploring and implementing argumentation-based strategies in their science education. This difference in the number of studies between countries may also reflect variations in educational policies, research resources, and academic interest in argumentation in science learning.

4. Conclusions

Research on argumentation in science learning has shown an increasing trend in recent years, with Indonesia and Turkey being the countries with the largest number of studies. Various argumentation approaches, such as Argumentation-Driven Inquiry (ADI), Toulmin's Argumentation Pattern, and Argumentation-Promoted Interactive Simulation, have been demonstrated to enhance students' critical thinking skills, conceptual understanding, and science literacy. Most studies employed a quantitative approach with a quasi-experimental design, demonstrating the effectiveness of argumentation-based interventions in improving learning outcomes. In addition, many studies involved students as the main participants, followed by prospective teachers and educators, which emphasizes the importance of strengthening argumentation at various levels of education.

5. Suggestions

Based on these findings, it is recommended that educators incorporate more argumentation-based strategies into science learning to enhance students' critical thinking skills and science literacy. In addition, research in countries where studies on argumentation in science learning are still limited should be expanded to gain a deeper understanding of argumentation implementation in diverse cultural contexts and educational systems. Mixed-methods approaches and development-based research also need to be further developed to provide a more comprehensive picture of the effectiveness of argumentation-based learning models.

The implication of this research is the need for curriculum design that is more supportive of argumentation in science learning, both at the school and university levels. Additionally, training for teachers and prospective teachers on argumentation-based learning strategies should be strengthened to enable them to apply these strategies effectively in the classroom. Thus, argumentative approaches in science learning not only improve student learning outcomes but also shape a generation that is more critical, reflective, and has high science literacy, which is necessary in facing global challenges in the future.

6. Co-Author Contribution

The authors declare that they have no conflicts of interest related to this article. All authors were actively involved in enhancing the manuscript’s structure, content, and overall quality.

7. Acknowledgements

The authors acknowledge with gratitude the financial support provided by LPDP (Indonesia Endowment Fund for Education) for the publication of this article. Appreciation is also extended to the Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, and the Graduate Institute of Science Education, National Taiwan Normal University, for their continuous support and encouragement in the publication of this article.

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