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THE RELATIONSHIP BETWEEN CRITICAL THINKING AND SCIENTIFIC ARGUMENTATION IN SCIENCE LEARNING

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ABSTRACT

The study aims to examine the relationship between critical thinking and scientific arguments in science learning. Critical thinking and scientific argumentation help to understand and apply scientific concepts to science learning. The research method is a systematic literature review of articles published between 2012 and 2022 and indexed in Scopus at least Quartile 2 (Q2), so the article's quality is high. In search results for related articles published in the last decade, the study found 17,800 articles, but only 11 met the criteria focused on improving critical thinking skills through various methods and strategies, including the use of newspaper articles, scientific argumentation, and visualization techniques. The findings from literature reviews show an interdependent relationship between critical thinking and scientific arguments, and both significantly contribute to the study of science. Several methods exist to train and develop critical thinking and scientific arguments in science learning: argument and concept maps, essential reading activities, argument or speech texts, discussion activities, analytical questions, learning technologies, and specific learning strategies. This study concludes that critical thinking and scientific argument are interrelated skills that contribute to learning. The complex relationship between critical thinking and scientific arguments in science learning can encourage deeper learning and understanding of concepts.

Keywords: critical thinking; scientific argumentation; science learning; higher-order thinking skills; 21st-century skills

INTRODUCTION

Critical thinking skills and scientific argumentation play an essential role in science learning. Scientific argumentation is a practice that helps make critical thinking skills and dispositions visible, accessible, and assessable in practice through the construction of arguments, counterarguments, and rebuttals in the context of authentic thinking together with others (Rapanta & Iordanou, 2023; Chen et al., 2024). However, little research still examines the relationship between critical thinking and scientific argumentation in science learning. Therefore, it is imperative to investigate the relationship between critical thinking and scientific argumentation in science learning based on a literature review of previous research. The urgency to study the relationship between critical thinking and scientific argumentation in science learning is essential because argumentation has a significant contribution to developing critical thinking skills with distinctive

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characteristics: assessing sources of information, evaluating arguments, and producing arguments and presenting them (Hidayati et al., 2023; Suradika et al., 2023). Scientific argumentation skills make students more active in arguing by expressing the meaning or meaning of the learning experience provided and being able to construct the definition or meaning of their knowledge and bring up their critical thinking skills (Probosari et al., 2022).

Critical thinking is one of the four main personal competencies that students must have because it is an essential competency to contribute to education and professional achievement in the 21st century (Bourn, 2018; Kusumoto, 2018; Basri et al., 2019; Shaw et al., 2020; van Laar et al., 2020; Bağ & Gürsoy, 2021; Kocak et al., 2021; Kuloğlu, 2022; Can et al., 2024; Chen et al., 2024a). This competency is needed to apply cognitive skills, such as analysis, application, and evaluation, when thinking at a higher level (Alsaleh, 2020). Critical thinking requires mental abilities and attitudes that adapt to the demands of the 21st century. Critical thinking involves making decisions based on the information obtained and communicating it with adequate thought and reasoning (van Laar et al., 2020). From a psychological point of view, critical thinking requires mastery of a set of mental skills and dispositions that can be generalized to different contexts (Abrami et al., 2008; Monteiro et al., 2020). The disposition part in question includes several qualities: truth-seeking skills, open-mindedness, systematic analysis, maturity, curiosity, and self-confidence (Ismail et al., 2022). This part can be understood as a cognitive ability or character that includes the social and emotional aspects necessary to make informed decisions and communicate them rationally.

Critical thinking is a must-have skill for solving problems, gathering evidence, and evaluating information (Song et al., 2024). It is a critical competency to improve thinking, learning, and working (Nguyen et al., 2023). Critical thinking is considered a foundational core competency, which is interdependent and advanced with other competencies, helpful in enhancing cultural understanding and inheritance, fostering innovative capabilities, and increasing the efficiency of communication and cooperation (Zhao et al., 2018; Wei, 2020; Chen et al., 2024b). This skill is also often associated with scientific argumentation skills. Critical thinking skills, reasoning, and understanding concepts are closely related to scientific argumentation (Alfarraj et al., 2023). Scientific argumentation is a skill that plays a vital role in the development of students' knowledge, and it has attracted the interest of decision-makers worldwide (Henderson et al., 2018; Ho et al., 2019; Admoko et al., 2021; Guilfoyle & Erduran, 2021). These skills also have particular interest among educational researchers (Zhu et al., 2017; Grooms et al., 2018; Chen et al., 2019; Perdana et al., 2019; Ping et al., 2020; Governor et al., 2021; Tang, 2022; Hendratmoko et al., 2023, 2024). It can be concluded that scientific argumentation is a skill that plays an essential role in developing students' knowledge, making it the main focus of policymakers in education and educational researchers in various parts of the world.

Scientific argumentation is one skill that plays a vital role in science learning. This skill involves collaboration and regulation of learning (Lobczowski et al., 2020; Zheng et al., 2023). Scientific argumentation can help improve critical thinking skills in several ways, such as assessing sources of information, evaluating arguments, communicating arguments, and presenting them (Roviati & Widodo, 2019). Argumentation can also be interpreted as a complex and time-consuming process because it is identical to the activity of arguing. Hence, it requires the construction of rational and reasonable arguments (Archila et al., 2021). Integrating scientific argumentation into science learning can be challenging to implement. In order to provide opportunities for students to participate in scientific argumentation, teachers must restructure learning habits from traditional pedagogical approaches to learning that enable students to create and critically evaluate fact-based ideas so that they not only focus on what they know but also on how they find out (Kurniawan et al., 2021; Putra et al., 2021).

The rational relationship between critical thinking skills and scientific argumentation ensures a conceptual correlation in science learning. Critical thinking skills and scientific argumentation are intertwined. Critical thinking skills allow students to evaluate and understand data well (Coote, 2023). In comparison, scientific arguments provide a framework for students to compile and communicate findings effectively (Reuter, 2023). This relationship ensures that students receive information passively and actively engage in the evidence-based and logic-based science learning process.

Based on the background, it is essential and urgent to research the relationship between critical thinking and scientific argumentation in science learning, considering that argumentation and critical thinking are an essential part of its development and assessment (Baze et al., 2023a)

so that it can help achieve transformation where teachers can design new learning models, providing a learning environment that optimizes the role of technology, and using learning models that can be used to support and increase student participation in applying scientific arguments to classroom learning activities (Mithen et al., 2021). Scientific argumentation skills can help solve problems, understand the learning process, and develop higher-order thinking skills, such as critical thinking (Giri & Paily, 2020).

Based on the problem and urgency of the research, this study aims to examine the relationship between critical thinking and scientific argumentation in the context of science learning. Hopefully, this research can also enrich knowledge and become input and reference in understanding the complex relationship between critical thinking and scientific argumentation in science learning for future academics and researchers. This research is also expected to benefit teachers and lecturers in increasing knowledge about alternatives that can be used to develop and improve critical thinking skills and scientific argumentation in science learning. Teachers and lecturers must direct their students to analyze science material deeply, fostering a systematic thinking attitude. It is hoped that students' thinking skills can help them organize their ideas well to increase their argumentation skills.

METHODS

This research's methodology is a systematic review of the literature. Reviewing literature involves collecting library data, reading and recording, and managing research materials (Petticrew & Roberts, 2008). Several reputable journal articles indexed by Scopus from 2012 to 2022 were selected. Scopus, a well-known journal index, was used to select articles. Scopus articles are high quality and worth considering. Based on related literature, this research examines the relationship between critical thinking and scientific argumentation in science learning. In this research, there are seven steps in the review process: (1) determining the research question; (2) determine criteria; (3) produce a review protocol; (4) search, filter, and select; (5) analyze and interpret; (6) produce articles; (7) disseminate (Bennett; et al., 2005; Borrego et al., 2014; Winarno et al., 2020). Here is a systematization of several stages of initialization using the Vosviewer application and defining three keywords (critical thinking skills in science learning, arguments in scientific learning, and the relationship between critical thinking and scientific argument in science studies); setting eligibility criteria; finding and selecting articles; reviewing articles in depth; and disseminating findings (Figure 1).

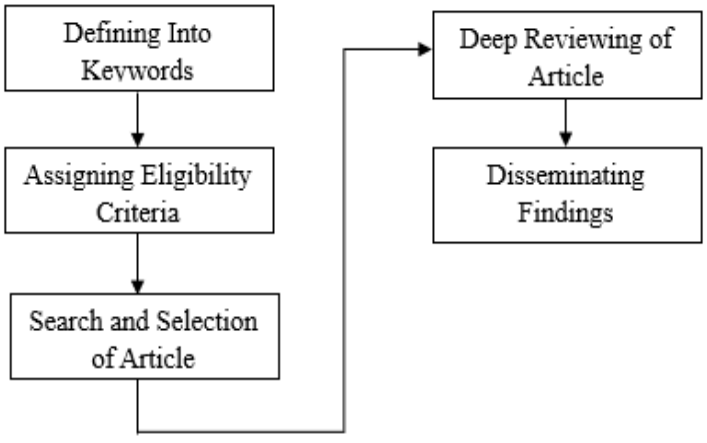

Figure 1. Modification of Systematic Review

Articles relevant to the research were identified in Scopus journal articles. Search and selection in the article review process used the PRISMA diagram (Liberati et al., 2009; Moher et al., 2009), as presented in Figure 2.

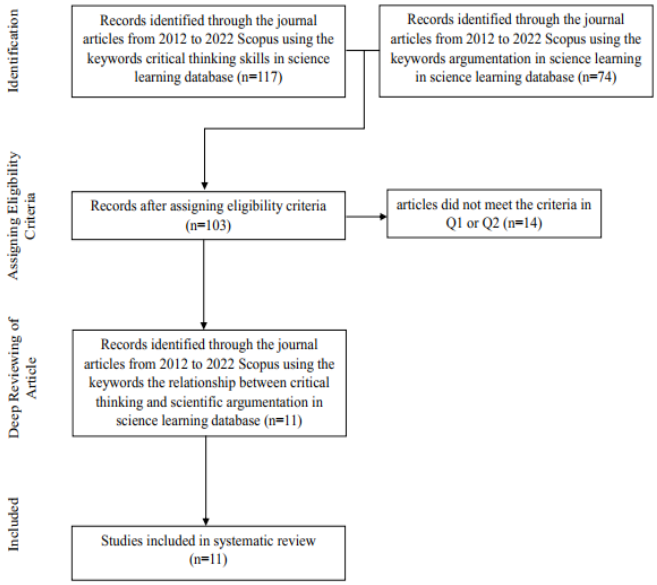

Figure 2. PRISMA Diagram

Mapping article data related to critical thinking and argumentation skills in science learning is divided into three keywords. First, using the keyword "critical thinking skills in science learning," 117 articles were mapped. Second, the keyword "argumentation in science learning" in 74 articles was mapped. Next, sorting was carried out based on the specified criteria, and 14 articles that did not meet the criteria in Q1 or Q2 were obtained. Thus, 103 articles met the mapping requirements. Figure 3 is the result of mapping with Scopus.

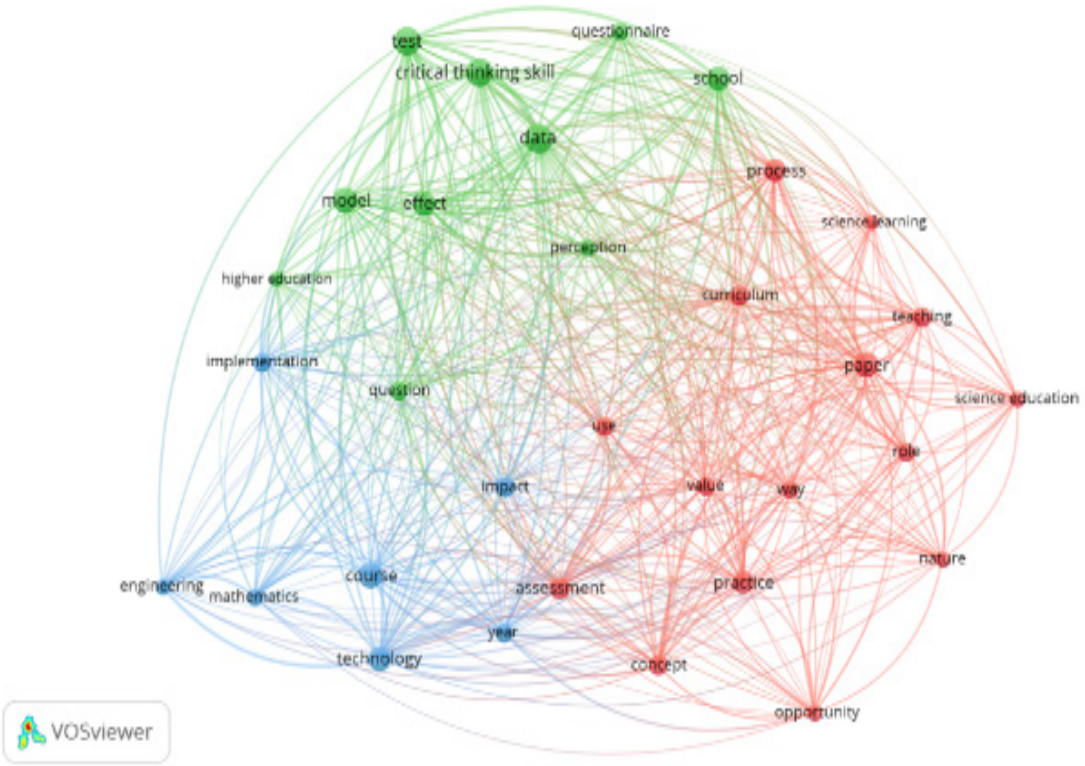

Figure 3. Concept Mapping Related to Critical Thinking Skills in Science Learning

Figure 3 depicts the science education process to improve students' comprehension of scientific ideas. Developing critical thinking abilities enables students to comprehensively grasp these concepts and effectively apply their knowledge across various contexts. In addition, the students' capacity to analyze information, assess arguments, and draw conclusions based on evidence enables them to establish connections between knowledge and engineering design. Critical thinking is an essential element of the learning process as it cultivates skills in problem-solving, informed decision-making, and the capacity to construct clear and logical arguments. Integrating critical thinking abilities into higher education science, design, and technology curricula can enhance students' readiness to tackle intricate difficulties in the professional realm and make valuable contributions to advancing societies. The results of mapping articles from Scopus are followed up by writing in Table 1.

Table 1. Selected Articles for Review

No.	Journal name	F	%	Indexed by	H-index 2021 (SJR)
1	International Journal of STEM Education	6	5,8	Scopus: Q1	27
2	Jurnal Pendidikan IPA Indonesia	16	15,6	Scopus: Q2	20
3	CBE Life Sciences Education	11	10,7	Scopus: Q1	74
4	Higher Education Research and Development	3	2,9	Scopus: Q1	76
5	Instructional Science	5	4,9	Scopus: Q1	79
6	International Journal of Instruction	7	6,8	Scopus: Q2	26
7	International Journal of Science and Mathematics Education	5	4,9	Scopus: Q1	45
8	International Journal of Science Education	9	8,8	Scopus: Q1	115
9	Journal of Geoscience Education	13	12,6	Scopus: Q2	37
10	Learning and Individual Differences	1	0,9	Scopus: Q1	89
11	Metacognition and Learning	2	1,9	Scopus: Q1	57
12	Research in Learning Technology	2	1,9	Scopus: Q1	30
13	Research in Science Education	7	6,8	Scopus: Q1	56
14	Science Education	3	2,9	Scopus: Q1	121
15	Studies in Philosophy and Education	2	1,9	Scopus: Q1	33
16	Thinking Skills and Creativity	11	10,7	Scopus: Q1	49

The results of mapping articles from Scopus are followed up by writing in Table 1. This table includes the journal name, number of articles, percentage, indexed, and H-index 2021. The following data collection is mapped with the keyword "argumentation in science learning." The mapping data presentation is in Figure 4.

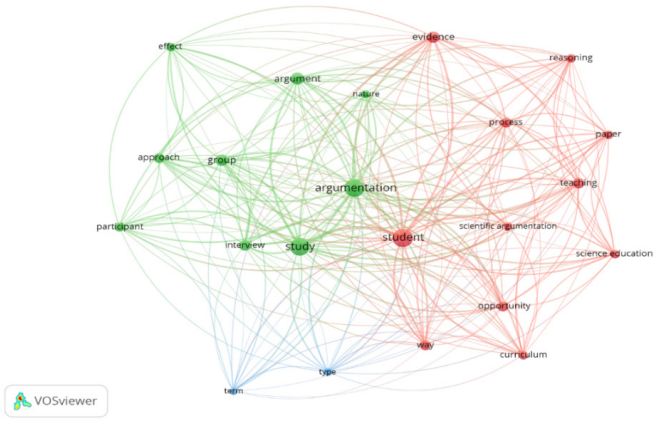

Figure 4. Concept Mapping Related to Argumentation in Science Learning

Figure 4 illustrates that in science, students' comprehension of concepts is often enhanced when they are required to articulate and justify their thoughts. Argumentation compels students to think critically about scientific concepts and their interconnections. Argumentation encompasses essential cognitive abilities, including examining, assessing, and applying logical reasoning. Science learning is critical for kids because it enables them to cultivate the skill of assessing information and making well-informed judgments. Enhancing students' argumentation skills improves their ability to communicate scientific information effectively. This encompasses the capacity to effectively communicate ideas, attentively consider and address others' arguments, and express one's thoughts logically and organized. Argumentation encourages pupils to develop problem-solving skills by prompting them to consider alternative viewpoints and potential solutions. Contemporary science curricula strongly emphasize the significance of argumentation in scientific education. This aligns with the Next Generation Science Standards (NGSS) methodology, which emphasizes scientific and engineering practice. Integrating argumentation skills into science instruction enables students to cultivate a comprehensive and profound understanding of science. Additionally, it enhances their capacity to communicate and collaborate effectively within scientific and professional settings. More detailed information regarding the mapping results is presented in Table 2.

Table 2. Selected Articles for Review

No.	Journal name	F	%	Indexed by	H-index 2021 (SJR)
1	International Journal of STEM Education	2	2,7	Scopus: Q1	27
2	Jurnal Pendidikan IPA Indonesia	1	1,3	Scopus: Q2	20
3	CBE Life Sciences Education	2	2,7	Scopus: Q1	74
4	Instructional Science	5	6,8	Scopus: Q1	79
5	International Journal of Instruction	1	1,3	Scopus: Q2	26
6	International Journal of Science and Mathematics Education	10	13,5	Scopus: Q1	45
7	International Journal of Science Education	36	48,7	Scopus: Q1	115
8	Journal of Geoscience Education	2	2,7	Scopus: Q2	37
9	Learning and Individual Differences	1	1,3	Scopus: Q1	89
10	Research in Science Education	9	12,2	Scopus: Q1	56
11	Science Education	5	6,8	Scopus: Q1	121
	Total	74	100		

The third mapping is searching for articles published from 2012 to 2022 to review. Articles were also searched directly on international journal websites. The keyword was "the relationship between critical thinking and scientific argumentation in science learning." Based on the search results, around 17,800 articles were found, but only 11 articles met the criteria. The number of articles in each journal is symbolized by the letter "F" in the table. Table 3 presents the selected articles for review.

Table 3. Selected Articles for Review

No.	Journal name	f	%	Indexed by	H-index 2021 (SJR)
1	Thinking Skills and Creativity	4	36.36	Scopus: Q1	49
2	Science & Education	1	9.09	Scopus: Q1	49
3	PLOS ONE	1	9.09	Scopus: Q1	367
4	Educational Psychologist	1	9.09	Scopus: Q1	135
5	International Journal of Science Education	2	18.18	Scopus: Q1	115
6	Contemporary Educational Psychology	1	9.09	Scopus: Q1	113
7	SAGE Open	1	9.09	Scopus: Q2	41
	Total	11	100		

Table 4 presents seven international journals indexed by Scopus. The selected journal must be found in the Scimago journal system and have a high H-index, as stated by Scimago Journal. Thus, all articles selected for this research were of excellent quality.

Table 4. List of Articles that Met the Criteria

Year	Authors	Title	Journal name
2013	Oliveras et al.	The Use of Newspaper Articles as a Tool to Develop Critical Thinking in Science Classes	International Journal of Science Education
2014	Dwyer et al.	An integrated critical thinking framework for the 21st century	Thinking Skills and Creativity
2015	Bathgate et al.	The Learning Benefits of Being Willing and Able to Engage in Scientific Argumentation	International Journal of Science Education
2017	Cook et al.	Neutralizing misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence.	PLOS ONE
2017	Wang & Seepho	Facilitating Chinese EFL Learners' Critical Thinking Skills: The Contributions of Teaching Strategies	SAGE Open
2019	Rodríguez et al.	Flipped classroom: Fostering creative skills in undergraduate students of health sciences	Thinking Skills and Creativity
2020	Christodoulou & Diakidoy	The contribution of argument knowledge to the comprehension and critical evaluation of argumentative text	Contemporary Educational Psychology
2020	Ngajie et al.	Investigating the effects of a systematic and model-based design of computer-supported argument visualization on critical thinking	Thinking Skills and Creativity
2020	Giri & Paily	Effect of Scientific Argumentation on the Development of Critical Thinking	Science & Education
2021	Kaeppel	The influence of collaborative argument mapping on college students' critical thinking about contentious arguments	Thinking Skills and Creativity
2021	Nussbaum	Critical integrative argumentation: Toward complexity in students' thinking	Educational Psychologist

Dwyer et al. (2014) and Bathgate et al. (2015) align with constructivist principles that emphasize active learning and the importance of students building their understanding through engagement and interaction. Argumentation is a crucial constructivist strategy that facilitating more profound understanding and knowledge retention (Loinaz & Agundez, 2024). Social interaction is fundamental to cognitive development. Engaging in argumentation allows students to convey their thoughts in the face of different viewpoints and refine understanding through collaborative dialogue(Gao et al., 2024).

The data from this research were analyzed descriptively. Data was categorized as tables and figures based on the specified search framework. Next, the data is discussed thoroughly and in-depth. Based on a literature review of previous studies, this research focuses on determining the relationship between critical thinking and scientific argumentation in science learning.

RESULTS AND DISCUSSION

The data obtained, "critical thinking skills in science learning," shows that the research focuses on learning from this keyword (Figure 5).

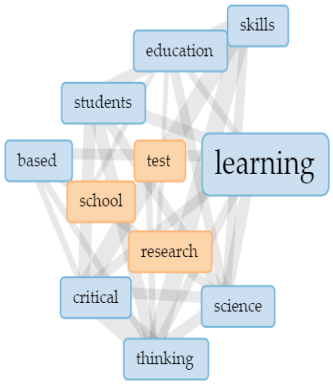

Figure 5. Mapping of "Critical Thinking Skills in Science Learning" Keyword

Figure 5 shows the mapping of the "Critical Thinking Skills in Science Learning" keyword commonly used in research. The research results show that the keywords commonly used in "Critical Thinking Skills in Science Learning" are learning, students, science, critical, and thinking. Learning is the primary goal of any educational endeavor, including science learning (Olivares et al., 2017; Sharples et al., 2017). Science learning emphasizes acquiring knowledge, understanding concepts, and developing skills through active involvement. The focus is empowering students to think critically, analyze information, and make judgments. The emphasis is on student-centered learning, encouraging active participation and independent thinking (Dwyer et al., 2014; Hendratmoko et al., 2023). Science learning fosters scientific literacy and enables students to evaluate scientific claims, analyze data, and engage in scientific inquiry. Critical thinking involves questioning assumptions, recognizing bias, and applying reasoning to form well-supported conclusions. Critical thinking is essential to scientific inquiry and decision-making (Ngajie et al., 2020). Thinking encourages students to engage in higher-order thinking skills, such as analysis, evaluation, inference, and reflection. Critical thinking allows students to go beyond rote memorization and simple understanding (Rodríguez et al., 2019). These keywords reflect the essence of "Critical Thinking Skills in Science Learning" by covering vital elements of an educational approach and highlighting the interrelationship between learning, students, science, critical thinking, and active cognitive processes. These five keywords were explored more intensely over the last ten years, as presented in Figure 6.

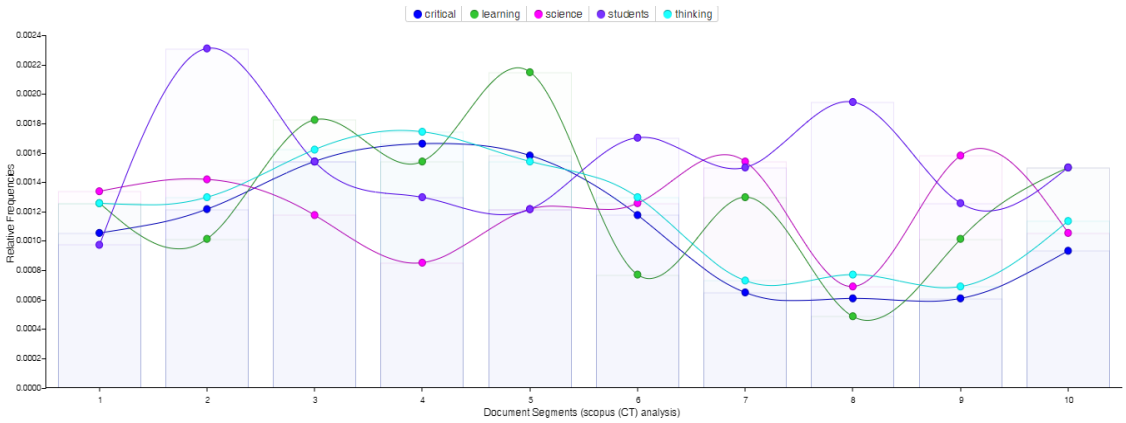

Figure 6. Abstract Analysis of Trends in Critical Thinking Skills in Science Learning

Figure 6 shows the frequency of increase in student keywords in the second, sixth, eighth, and tenth years. The frequency of critical keywords in the first to fourth years continues to increase and decreases in the fifth to ninth years until the tenth year, when it increases again. This is also the same as keyword thinking. The frequency of learning increases in the third, fifth, seventh, ninth, and tenth years. The frequency of science keywords increased in the second, fifth, seventh, and ninth years. The following research results are arguments in science learning based on the abstract mapping of the results shown in Figure 7.

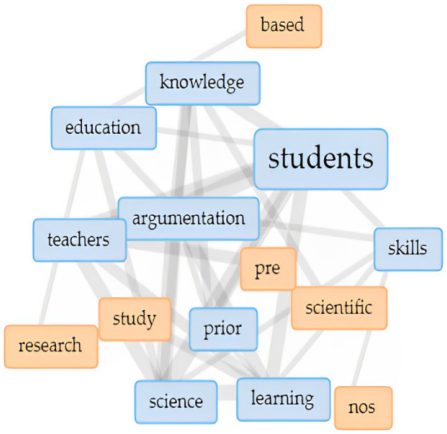

Figure 7. Abstract Content Mapping of "Argumentation in Science Learning"

Figure 7 shows keyword mapping frequently used in research with student-focused arguments. The keywords used in writing abstracts are students, arguments, teachers, science, and learning. Students are the main participants in science learning. Understanding how students engage in argumentation in the context of science education is critical to identifying effective teaching strategies, encouraging active learning, and improving students' scientific reasoning. Argumentation refers to constructing, evaluating, and defending arguments based on evidence and logical reasoning (Bathgate et al., 2015). It plays a vital role in science learning because it fosters critical thinking, scientific discourse, and the development of scientific explanations. The abstract will likely explore the role of argumentation in the science classroom and its impact on students' learning outcomes.

There are two types of argumentation in science learning: one specific to science itself and the other based on learning requiring dialogic interaction (Hendratmoko et al., 2023). The teacher is a crucial figure in facilitating argumentation in science learning. Abstracts may discuss strategies, pedagogical approaches, and professional development initiatives that empower teachers to effectively improve argumentation skills among their students (Wang & Seepho, 2017). It can also explore teachers' challenges and opportunities when incorporating argumentation into science teaching. Science represents the subject matter and context in which argumentation is applied. Abstracts can highlight specific scientific topics, such as biology, physics, or chemistry, and explore how argumentation is used to deepen students' understanding of scientific concepts, engage them in scientific inquiry, and develop their scientific literacy (Giri & Paily, 2020).

Learning is the ultimate goal of science education, and the abstract is likely to discuss how argumentation contributes to the learning process (Cook et al., 2017). This might explore the impact of argumentation on students' conceptual understanding, problem-solving skills, scientific reasoning, and overall engagement in science learning. The abstract may also discuss the potential benefits of an argumentation-based approach over traditional teaching methods. These keywords reflect key elements and themes related to argumentation in science learning. They provide a brief overview of the main focus areas and research objectives discussed in the abstract, highlighting the importance of students, argumentation, teachers, science, and learning in this particular topic. Developing the ability to engage in argumentation is essential in science education. Students are encouraged to propose hypotheses, substantiate their assertions with evidence, and justify their views through classroom debates and experiments. Higher education necessitates the development of sophisticated reasoning abilities, which are employed in research, scientific writing, and academic presentations. Students frequently participate in seminars, conferences, and research projects that necessitate the capacity to construct and sustain intricate arguments. These five words were then studied in depth over the last ten years, and the results are presented in Figure 8.

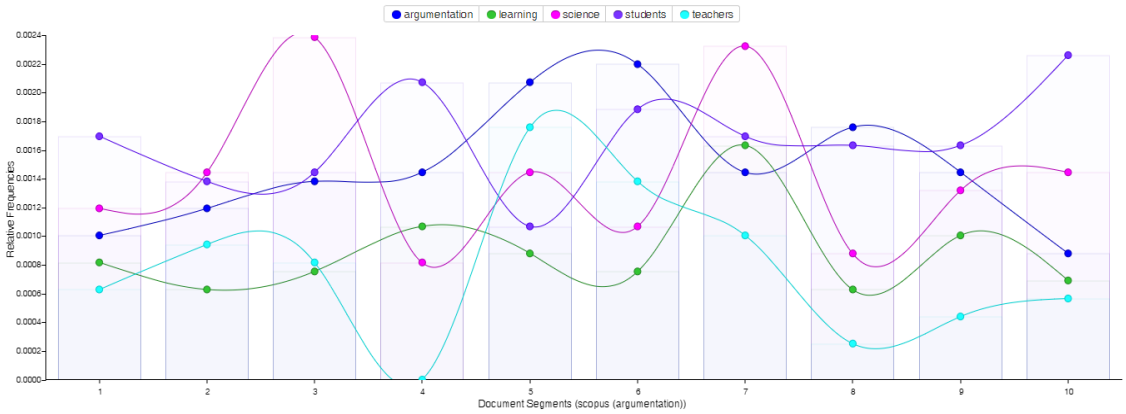

Figure 8. Abstract Analysis of Argumentation Tendencies in Science Learning

Figure 8 shows the frequency of trends that have appeared in argumentation, learning, science, students, and teachers over the last ten years. The "argumentation" keyword frequency increased from the first to the sixth year and again in the eighth year. The frequency of the keyword "learning" increased in the third, fourth, seventh, and ninth years. The "science" keyword frequency increased from the first year to the third, fifth, seventh, ninth, and tenth years. The "student" keyword frequency increased in the third year to the third year and increased again in the sixth and tenth years. The "teacher" keyword frequency increased in the second, fifth, and ninth to tenth years. Based on the results of a search for articles discussing the relationship between critical thinking and scientific argumentation in science learning in the last ten years, 11 articles were published in seven reputable international journals. Articles that met the criteria are presented in Table 4. Figure 9 shows a trend in the number of publications between critical thinking skills and arguments in science learning, where in 2012–2014, there was an increase in critical thought skills and argument publications in scientific learning. In 2015, there was a decrease in the publication of critical thinking skills and arguments in science learning, but the publication of critical thinking skills continued to decline until 2018 and again increased in 2019–2021. The number of arguments published in science learning in 2016 began to rise in 2018, but in 2019–2020, there was a decline and a further increase in 2021.

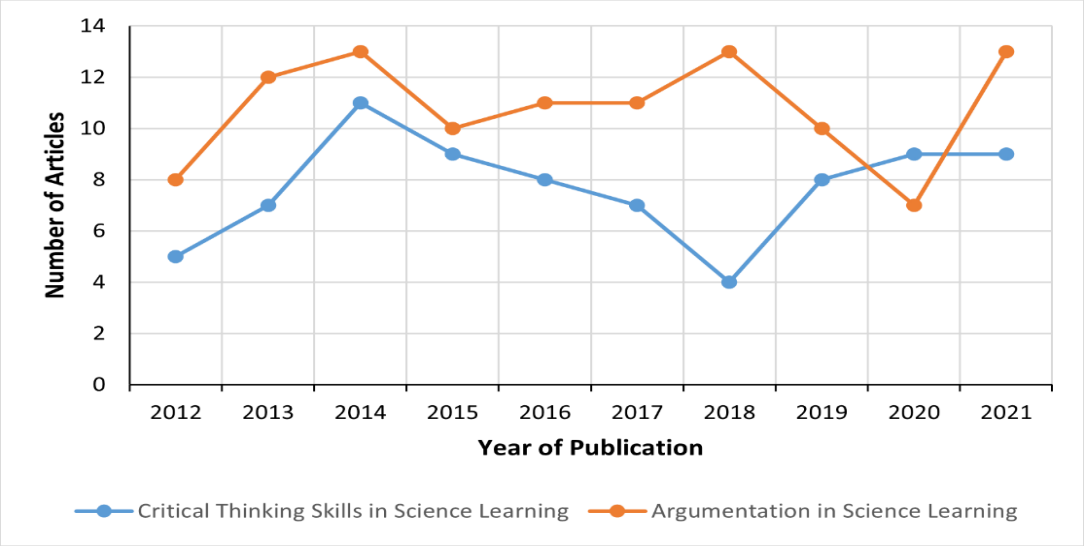

Figure 9. Critical Thinking and Argumentation Skills in Science Learning

Critical thinking and scientific argumentation are connected in a literature study of eleven articles that met the requirements. Critical thinking requires objective and rational analysis, evaluation, and interpretation. In science learning, scientific argumentation uses data and logic to support or refute a thesis. Scientific reasoning teaches students how science supports convincing arguments. Students can identify and evaluate scientific arguments in science news (Oliveras et al., 2013). Science education emphasizes critical thinking. Students can assess science facts by using critical thinking skills. Scientific debates can teach critical thinking because students must identify and evaluate arguments. The implementation of debate in learning activities can foster acceptance of diverse perspectives, encourage critical reflection on one's previous beliefs, and encourage the development of reasoning through challenging and refuting opposing arguments (Rodger & Stewart-Lord, 2020; Guo et al., 2023; Khoiri et al., 2023). However, students often struggle to apply critical thinking to text analysis, accept information without question, and set goals (Oliveras et al., 2013). Science teachers must foster critical thinking. Teachers should give students time to solve difficulties, ask meaningful questions, and debate. Student debate and interaction also encourage critical thinking (Oliveras et al., 2013).

Critical thinking is vital in many aspects, such as society, the work environment, and the classroom (Double et al., 2023). Critical thinking involves evaluating the credibility, relevance, and logical strength of propositions and arguments and their strengths and weaknesses, which indicates how well students think critically (Dwyer et al., 2014). The need for clear indicators to measure critical thinking skills with scientific arguments and the many different conceptualizations of critical thinking makes it difficult for researchers and teachers to build an integrated theore-

tical framework to train and measure them (Dwyer et al., 2014). Online argument mapping improves critical thinking, organizes and analyzes information, and improves critical thinking (Astawan et al., 2023). Learning interventions that influence critical thinking skills and dispositions can improve individuals' critical thinking skills and enhance their ability to develop and understand scientific arguments (Agustina & Putra, 2022a). Dwyer et al. (2014) also found that argument mapping, a visual method for analyzing and visualizing arguments, improved students' critical thinking skills. The findings of this research are supported by Davies (2009), who found that argument mapping helps students organize and analyze information to identify weaknesses in arguments, thereby improving their critical thinking skills and strengthening arguments.

The production and evaluation of argumentative discourse rarely consists of opinions whose claims can be precisely assessed as true or false (Flouris et al., 2023). In practice, scientific argumentation requires critical thinking because people must evaluate evidence, identify weaknesses, and construct consistent and logical arguments to develop a strong argument (Bathgate et al., 2015). Scientific argumentation requires critical thinking because one must evaluate evidence, identify weaknesses, and construct consistent and logical arguments to develop a strong argument (Agustina & Putra, 2022b). The solution is to create a classroom environment that is supportive and safe for students to debate, where teachers can create a classroom culture that encourages students to participate in scientific discussions and debates without fear of rejection or negative social consequences. Teachers can also clearly explain the benefits of debating in science and how it can help students learn (Bathgate et al., 2015; Hidayati et al., 2023).

Scientific argumentation and critical thinking are interrelated and influence each other in understanding and evaluating scientific information (Probosari et al., 2022; Rapanta & Iordanou, 2023). Scientific argumentation requires critical thinking to produce solid and logical arguments, while critical thinking requires understanding scientific argumentation to analyze and evaluate information objectively and rationally (Cook et al., 2017). Lack of knowledge, atmosphere, or engagement can cause students to lose interest in learning. High work pressure or school support can also reduce teacher motivation. Students become disengaged in learning due to a lack of interaction with teachers and classmates, opportunities to actively participate, or a lack of relevance to everyday life (Cook et al., 2017). Providing relevant and exciting content, rewards and positive reinforcement, an inclusive and supportive learning environment, and opportunities to actively participate in learning can motivate students and teachers. Real examples, visualizations, and group discussions can help students understand concepts. Teachers can also give students more time to master challenging subjects and provide additional reading material. Through conversation, teachers can foster collaboration and interaction (Cook et al., 2017).

In general, teaching critical thinking aims to encourage students to express their opinions freely and develop their ability to examine several opposing points of view (Maor et al., 2023). Critical thinking requires analyzing and evaluating arguments using logic and relevant evidence. Therefore, scientific argumentation involves justifying and supporting statements. Scientific argumentation can improve students' critical thinking skills by helping them understand social contexts from different points of view (Wang & Seepho, 2017). Confucian culture discourages students from criticizing and participating in class discussions and debates, thereby inhibiting critical thinking (Wang & Seepho, 2017). Concept maps can help students understand propositions in reading texts and their logical relationships. However, it requires creative thinking, which may be difficult for Confucian-influenced students who are used to rote learning. Group discussions can help students overcome these challenges (Wang & Seepho, 2017).

Scientific argumentation involves presenting and evaluating evidence and reasoning and making claims based on scientific principles and concrete evidence. This process makes students critical in analyzing and assessing the validity and reliability of the evidence and arguments presented so that they are effective. Therefore, scientific arguments and critical thinking are interconnected and support each other in obtaining scientific knowledge and understanding in learning (Rodríguez et al., 2019). The flipped classroom method can overcome students' scientific argumentation and critical thinking difficulties. The flipped classroom method can improve students' critical and creative thinking skills because they are involved in activities that encourage them to ask questions, investigate the causes and consequences of their observations, and produce high-quality questions that enable students to use the flipped classroom method, direct their learning, and develop critical and creative thinking skills, such as problem-solving, flexibility, and reflection on different perspectives (Rodríguez et al., 2019).

Critical thinking and scientific argumentation strengthen each other. Scientific argumentation requires critical thinking to produce solid and valid arguments, and critical thinking requires scientific argumentation to develop rational and logical thinking (Ngajie et al., 2020). Students need help recognizing and creating alternative decision-making and prob-

lem-solving methods. They may also need more evidence to make a judgment on the argument. Teachers need help to find alternative solutions to educational technology problems (Ngajie et al., 2020). Teaching students critical thinking skills can help. Teach them "verbal thinking," "argument analysis," "hypothesis testing," "probability and uncertainty," and "problem-solving and decision making." Teaching these skills helps students recognize and apply critical thinking in technology education (Ngajie et al., 2020). Teachers also need educational technology skills. Professional development for teachers in educational technology is essential to help them overcome challenges (Ngajie et al., 2020). Most students say argumentation helps them think critically and express their ideas (Ngajie et al., 2020).

Scientific arguments created during learning can display the efficacy of critical thinking (Giri & Paily, 2020). Integrating scientific arguments into education and recognizing the need for more active learning helps train students' critical thinking skills. Zain and Jumadi (2018) found that teachers had difficulty distinguishing the structural components and dialogic nature of arguments during class discussions and asking appropriate questions to help students engage in arguments, making it difficult to apply scientific argumentation in science learning (Giri & Paily, 2020). Students may also need help creating quality arguments using the six aspects of the Toulmin argument model (Giri & Paily, 2020). Students must practice the Toulmin reasoning model to overcome these challenges. Scientific reasoning is part of science education and can help students understand science learning. Teachers must enhance classroom learning to help students understand these skills (Giri & Paily, 2020).

Scientific argumentation is closely related to critical thinking because it requires students to construct logical arguments and support them with relevant evidence (Christodoulou & Diakidoy, 2020). Students need the teacher's help with time management and understanding of content. Teachers need help to provide immediate feedback and keep students engaged (Christodoulou & Diakidoy, 2020). Several solutions can overcome this problem. Video conferencing and other interactive online learning platforms are one way. This helps students communicate with lecturers and receive direct guidance. Teachers should also provide regular feedback via email or learning platforms to motivate students with challenges or interesting assignments. Student-teacher-parent collaboration is essential. Parents can help students navigate distance learning (Christodoulou & Diakidoy, 2020).

Critical thinking is a crucial research tool, a liberating force in education, and a powerful resource in the lives of individuals and communities (Uribe-Enciso et al., 2017; Anggraeni et al., 2023). Critical thinking involves the ability to analyze and evaluate arguments logically and rationally, as well as the ability to identify the weaknesses and strengths of those arguments. However, scientific arguments use evidence and logic to support claims or hypotheses put forward in learning, so students must critically examine the validity and reliability of the evidence used and evaluate the strengths and weaknesses of the argument. Students and teachers need help to teach argumentation because teachers lack argumentation pedagogy and need help choosing learning models. Students struggle to create knowledge and meaning. Therefore, they need more time to think about what the teacher wants, which results in poor arguments (Nussbaum, 2021). Teachers can assign assignments or activities that encourage students to generate more counterarguments and rebuttals, and they can use texts that present arguments on both sides of an issue to encourage students to do so. Because small group conversations help students communicate and reconcile conflicts (Nussbaum, 2021).

Critical thinking is a significant aspect of living life and must be part of the education system to enable students to develop critical thinking skills (Tanti et al., 2020; Mohammadi et al., 2023). Critical thinking helps students assess objectively and produce strong and comprehensive arguments in scientific reasoning (Kaeppel, 2021). Students from the South often make arguments haphazardly without paying attention to the structure of the argument, making it difficult for them to develop premises that support their argument. They also need to help understand hierarchical argument structures and require logical validation. Some students were silent, while others took over mapping the dispute. These students may not participate because they are too devoted to their beliefs or need more time to absorb and build their arguments (Kaeppel, 2021). Teachers can provide more precise and in-depth guidance on using argument mapping methods effectively to help students understand and overcome cognitive difficulties. When students are in group work, teachers can facilitate fair participation by allowing enough time for students to process and formulate their arguments (Kaeppel, 2021).

Scientific argumentation is closely intertwined with critical thinking, as evidenced by the findings of research and discussions. Scientific argumentation necessitates the use of critical thinking in order to generate robust and sound arguments. Conversely, critical thinking relies on scientific argumentation to cultivate rational and logical thinking (Ngajie et al., 2020). Therefore, teachers can provide more structured and repetitive training in constructing arguments

in stages with continuous practice to help students become more accustomed and skilled in constructing logical and structured arguments (Kaeppel, 2021). These structured and repetitive exercises can be carried out or applied in science learning by applying an appropriate approach, such as a scientific or engineering design process (EDP). Students are also facilitated by using learning technology and applying specific questions in discussion activities (Baze et al., 2023; Hidayati et al., 2023).

This research has uncovered novel characteristics that have received less attention in prior publications. For example, we discovered that integrating enhanced skills into science education significantly improves students' understanding of scientific processes. This finding offers a fresh outlook on the significance of argumentation in cultivating scientific reasoning abilities. Students participating in debate are compelled to engage in profound and analytical thinking, increasing their cognitive engagement and fortifying their comprehension of scientific concepts. Social learning theory is relevant in group projects in science courses, where students collaborate to accomplish intricate tasks and substantiate their discoveries through presentations and debates.

CONCLUSION

The complexity of the relationship between critical thinking and scientific argumentation in science learning can encourage deeper learning and understanding of concepts. Critical thinking and scientific argumentation correlate with science learning to develop analytical and evaluative skills important for understanding and applying scientific concepts. Many alternatives can be used to develop and improve critical thinking skills and scientific argumentation in the context of science learning: the use of argument maps and concept maps, critical reading activities, the use of argumentative text or discourse, discussion activities, the use of analytical questions, the use of learning technology, and the application of specific questions and learning strategies. Learning approaches that can be used as recommendations for learning are scientific and engineering design processes (EDP). Recommendations for further research include conducting direct experiments by measuring argumentation and critical thinking skills and continuing to investigate the relationship between the two based on correlation analysis. At the elementary school level, students can be taught the fundamentals of reasoning by engaging in light arguments on age-appropriate scientific issues. At the secondary level, students might engage in small-scale research projects that require them to formulate hypotheses, collect data, and construct arguments based on their results. College students can be motivated to participate in independent research that involves advanced scientific reasoning. They can engage in scientific conferences, compose research publications, and deliver academic lectures.

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