Improvement of Scientific Argumentation Skills of Students through Metacognitive Learning Strategies in the Context of Socioscientific Issues

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Abstract
The aim of this study was to assess the impact of implementing the metacognitive learning strategy within the context of socioscientific issues (SSI) on students' scientific argumentation skills. The metacognitive learning strategy used comprised four stages, namely preparing, doing, checking, and assessing & following-up, abbreviated as MLS-PDCA. In addition, a quasi-experiment was used with a pretest-posttest control group design. The participants included 96 students in the 11th grade MIPA (mathematics and sciences) program at public high schools in Malang, Indonesia. In the study process, one experimental class was instructed using the metacognitive learning strategy within the context of socioscientific issues (MLS-PDCA SSI), while two control classes received instruction through metacognitive learning strategy (MLS-PDCA) and expository learning strategy (ELS). The argumentation skills of students were assessed using the Rate Reaction Argumentation Test ($r = 0.894$). Data analysis techniques included the One-way ANOVA test and N-gain analysis. Consequently, the results showed that (1) students taught with MLS-PDCA SSI greatly improved in scientific argumentation skills compared to those in MLS-PDCA and ELS classes. (2) MLS-PDCA SSI proved to be an effective learning strategy for improving scientific argumentation skills, especially in the context of daily life-related learning materials. Conclusively, the development of scientific explanatory skills through metacognitive learning strategies contributed to the development of scientific argumentation quality.
Keywords: metacognitive learning strategy, socioscientific issues, scientific argumentation skills.

Совершенствование навыков научной аргументации у студентов средствами метакогнитивных стратегий обучения в контексте общественно-научной проблематики

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Аннотация
Цель данного исследования – оценить влияние реализации стратегии метакогнитивного обучения в контексте социально-научных проблем (SSI) на навыки научной аргументации студентов. Используемая стратегия метакогнитивного обучения состояла из четырех этапов: подготовка, выполнение, проверка и оценка, последующие действия (MLS-PDCA). Кроме того, был проведен квазиэксперимент с использованием схемы контрольной группы до и после тестирования. В нем приняли участие 96 учащихся 11-го класса по программе MIPA (математика и естественные науки) государственных средних школ в Маланге, Индонезия. В процессе обучения один экспериментальный класс обучался с использованием стратегии метакогнитивного обучения в контексте социально-научных вопросов (MLS-PDCA SSI), в то время как два контрольных класса обучались с использованием стратегии метакогнитивного обучения (MLS-PDCA) и стратегии разъяснительного обучения (ELS). Навыки аргументации студентов оценивались с помощью теста «Оцените реакцию на аргументацию» (r = 0,894). Методы анализа данных включали односторонний ANOVA-тест и анализ N-коэффициента усиления. Результаты исследования свидетельствуют о том, что (1) студенты, обучающиеся в рамках MLS-PDCA SSI, значительно улучшили навыки научной аргументации по сравнению с теми, кто учился в классах MLS-PDCA и ELS. (2) MLS-PDCA SSI зарекомендовала себя как эффективная стратегия обучения для совершенствования навыков научной аргументации, особенно в отношении учебных материалов, связанных с повседневной жизнью. Таким образом, развитие навыков научного объяснения с помощью стратегий метакогнитивного обучения способствовало повышению качества научной аргументации.
Ключевые слова: стратегия метакогнитивного обучения, социально-научные проблемы, навыки научной аргументации.

Introduction

The rapid progress in science, technology, and information during the 21st century is significantly impacting global life, particularly in the aspect of education. Typically, education plays a critical role in improving the quality of the workforce (Flaherty, 2020). Chemistry education is oriented toward cultivating 21st century skills such as critical thinking, creativity, collaboration, and communication (Weng et al., 2022). These skills are in line with the international education goal of promoting scientific literacy, which includes the ability to scientifically explain issues or phenomena, a fundamental aspect of scientific argumentation (Chin et al., 2016). A key measure to improve scientific literacy is the development of scientific argumentation skills (Sengul, 2019). Scientific arguments significantly contribute to improving knowledge and competency in scientific literacy (Chen & Liu, 2018). In the process of scientific argumentation, three scientific competencies are related to scientific literacy, namely problem identification, scientific explanation of phenomena, and the utilization of scientific evidence. Scientific argumentation consisted of claims or statements supported by scientific evidence and explanations (Faize et al., 2018).

Scientific argumentation is a critical component of science communication skills. Additionally, it comprises the ability to provide scientific explanations rooted in critical thinking, making claims supported by scientific evidence and logical reasoning. According to the framework developed by Toulmin, scientific argumentation includes essential elements, namely the claim, data, warrant, backing, qualifier, and rebuttal (Verheij, 2005). "Claim" is an idea, statement, conclusion, or opinion about a phenomenon, while "data" is the evidence, facts, or information supporting a claim. "Warrant" is the explanation connecting data to claims and "backing" is the supporting theory. "Qualifier" addresses the possibility or specific conditions of the warrant, and "rebuttal" is the refutation of the claim (Kaya et al., 2012). However, the current scenario shows limited scientific argumentation skills among Indonesian students due to the absence of conducive learning environments that promote scientific argumentation. The scientific argumentation skills of students, particularly in chemistry, are at a basic level (Sekerci & Canpolat, 2017). At this level, students can construct arguments with claims and scientific evidence but often lack scientific explanations (Deng & Wang, 2017).

Scientific argumentation is of great importance because society increasingly demands scientific evidence to solve everyday problems. To produce valid arguments, scientific evidence needs to be supported by logical and scientific explanations (McNeill, 2011). Mastering scientific argumentation is important in the study of science, as it focuses on both outcomes and the process by which phenomena occur (Nussbaum et al., 2008). Through scientific argumentation activities, students can have a deep understanding of concepts, propose, defend, and refute ideas while providing scientific explanations to seek the truth (Gamez & Erduran, 2018). Moreover, argumentation improves higher-order thinking skills, creative thinking, communication, problem-solving, and decision-making (Songsil et al., 2019). This implies that scientific argumentation should be a focal point in science education, specifically in chemistry.

Innovative learning methods are necessary to enhance the quality of scientific argumentation skills. Numerous researchers have made efforts to improve scientific argumentation. Songsil et al., (2019) developed scientific argumentation skills through the Argument Driven Inquiry (ADI) learning model. Diniya et al. (2021) applied analogy-based inquiry learning, and Jumadi et al. (2021) implemented argumentation-assisted problem-based learning.

One of the strategies to improve scientific argumentation skills is the application of metacognitive learning techniques. According to Dori et al. (2018), high-intensity context-based learning, integrated with metacognitive cues, improves scientific understanding. This strong scientific foundation equips students to provide problem solutions. Metacognitive learning aids students in identifying the strengths and weaknesses in their understanding, enabling them to take corrective actions to enhance their conceptual understanding. Metacognitive learning aids the development of students' scientific argumentation skills (Kuhn et al., 2013), critical thinking, and problem-solving abilities

(Kondakci & Aydin, 2013). The critical thinking and problem-solving abilities developed through metacognitive learning facilitate students in constructing robust scientific arguments (Demircioglu et al., 2022).

A promising metacognitive learning strategy for improving scientific argumentation skills is the PDCA metacognitive learning strategy. This approach comprises four steps, namely *preparing (P), doing (D), checking (C), and assessing* & *following-up (A)*. The PDCA metacognitive learning strategy promotes meaningful learning by connecting new material with prior knowledge that is consistent with learning objectives, focuses on student-centered learning, improves independent understanding, facilitates student interaction and collaboration, and enables the assessment of student abilities (Parlan et al., 2018).

Metacognitive learning has greater significance when connected to real-life phenomena. Context-based learning makes the subject matter more engaging and inspires students' curiosity (Yılmaz et al., 2022). The PDCA metacognitive learning strategy can be fused with socioscientific issues, which focus on science-based social problems. Socioscientific issues are often contentious and cause substantial debate, making them ideal for training scientific argumentation skills (Zeidler & Nichols, 2009). These issues find an excellent application in chemistry education, improving relevance, promoting scientific information absorption, developing scientific argumentation skills, and elevating scientific literacy (Bächtold et al., 2023).

Metacognitive learning strategies in the context of socioscientific issues can improve the ability to construct scientific explanations using various representations. In the context of chemistry, representations in the form of macroscale, submicroscale, and symbols are crucial for a comprehensive understanding of chemical concepts (Talanquer, 2011). Namdar and Shen (2016) argued that deploying representations in chemical discourse supports the quality of scientific argumentation, particularly in the explanatory domain. A multifaceted approach to learning, replete with diverse representations, heightens students' proficiency in explaining, interpreting, and depicting chemical phenomena at the molecular level, rendering argumentation structures more complex and scientifically rigorous.

A particular area of chemistry known as the reaction rate, demands the use of chemical representations to facilitate comprehension. The reaction rate material is inherently contextual and incorporates factual, conceptual, procedural, and metacognitive knowledge, necessitating a scientific thinking process for its understanding. Consequently, the subject of reaction rates is ideally suited for teaching scientific argumentation skills to students. The application of metacognitive learning strategies within the context of socioscientific issues for improving students' scientific argumentation skills has not been extensively explored. Therefore, this study assesses the impact of implementing the PDCA metacognitive learning strategy within the context of socioscientific issues (MLS-PDCA SSI) on students' scientific argumentation abilities.

Methodology

Study Aims

This study aims to analyze how metacognitive learning strategies, which are contextualized within Socioscientific Issues (SSI), impact students' scientific argumentation skills. In particular, the study intended to address the following research questions (RQ):

1) RQ1: Are there differences in students' scientific argumentation skills when comparing MLS-PDCA SSI, MLS-PDCA, and ELS learning?

2) RQ2: Does MLS-PDCA SSI lead to greater improvement in students' scientific argumentation skills compared to MLS-PDCA and ELS?

Study Design

The study was conducted for two months, from October to November 2022. A quasi-experimental design with a *pretest-posttest control group design* was used in this study. In addition, it comprised 96 11th-grade students from the Mathematics and Sciences (MIPA) program at public high schools in Malang, Indonesia, divided into three classes, namely an experimental class instructed with MLS-PDCA SSI, a control class 1 taught with MLS-PDCA, and a control class 2 taught with ELS. The instructional process in the experimental class and control classes followed a cyclical structure (four stages). It should be acknowledged that the SSI context was introduced in the "Preparing" stage for the experimental class. Learning activities with PDCA metacognitive strategies could be seen in Figure 1, while learning activities with ELS strategies were shown in Figure 2, and then the design was summarized in Table 1.

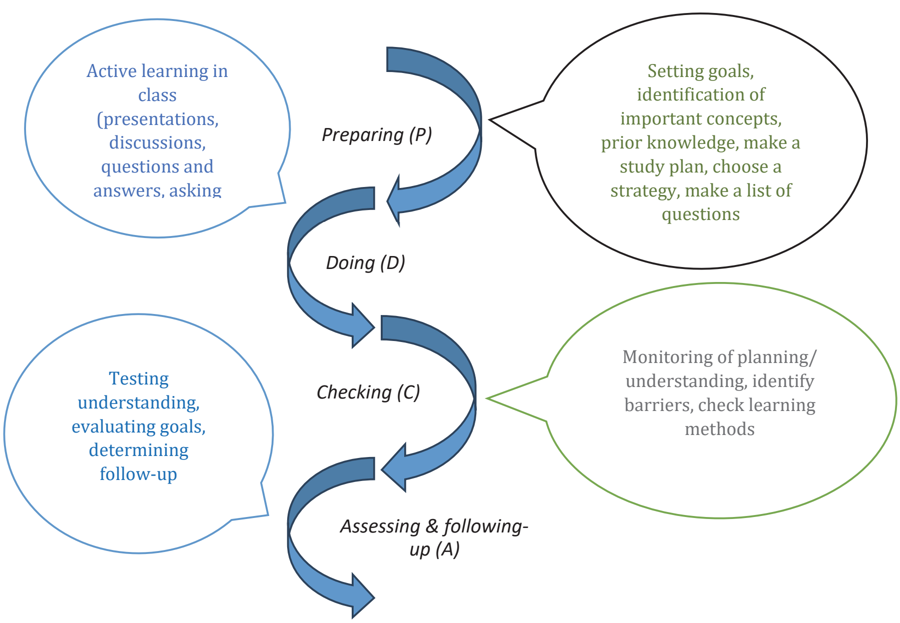


Figure 1. *Learning Activities with PDCA Metacognitive Strategies*

Table 1. *Research Design*

Subject	*Pre-test*	*Treatment*	*Post-test*
E	O_1	X_1	O_2
C1	O_1	X_2	O_2
C2	O_1	X_3	O_2

Information:
E : Experimental class
C1 : Control Class 1
C2 : Control Class 2

X1 : Learning with MLS-PDCA SSI
X2 : Learning with MLS-PDCA
X3 : Llearning with ELS
O1 : *Pre-test* using scientific argumentation ability test/ Rate Reaction Argumentation Test (RRAT)
O2: *Post-test* using a scientific argumentation ability test/ Rate Reaction Argumentation Test (RRAT)

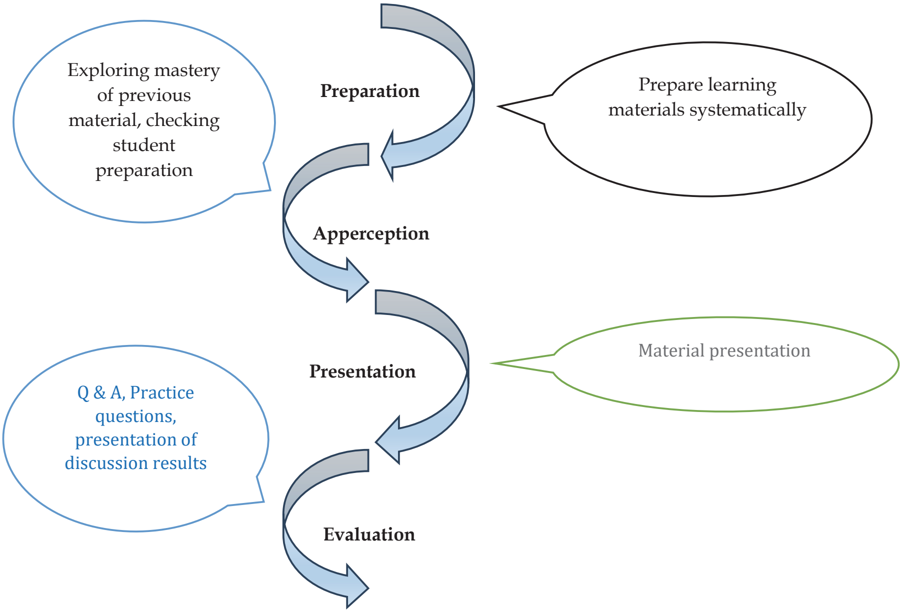


Figure 2. *Learning Activities with ELS*

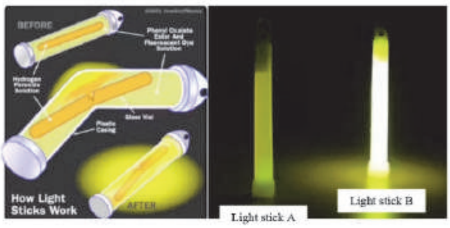
Participants

The participants included 96 11th grade students from the MIPA (mathematics and sciences) program at a public high school in Malang, Indonesia. These students showed similar cognitive abilities ($p = 0.985$; *Sig.* > 0.05) and were distributed across three classes, namely the experimental class (MLS-PDCA SSI), control class 1 (MLS-PDCA), and control class 2 (ELS).

Instrument

The Rate Reaction Argumentation Test (RRAT) was used to measure students' scientific argumentation skills during the pretest and posttest. The instrument comprised 8 essay questions designed to evaluate scientific argumentation skills based on Toulmin's argumentation framework, including claims, data, warrants, backing, qualifiers, and rebuttals. RRAT was validated by a chemistry lecturer and a chemistry teacher, and tested to determine its reliability. One example of an argumentation test item is presented in Appendix 2. Based on the pilot project conducted with 135 students, it was revealed that all the items were valid ($p < 0.05$) with reliability (the coefficient Cronbach's Alpha) of 0.894. A sample question from the Rate Reaction Argumentation Test, in the form of an essay could be seen in Figure 3 and Appendix 2. In Figure 3, the sample scientific argumentation questions were framed within the context of real-life phenomena, specifically light sticks commonly used by concertgoers.

Light Stick



Are you a fan of JKT48? or even the boy band BTS?. When the concert is held, of course it is no stranger to light sticks. Light sticks decorated with the writing or logo of each member who always adorn concerts with their beautiful light beams. The existence of this light stick makes the concert even more lively. The working principle of the light stick is very simple. A light stick consists of a thin glass bottle containing a solution of hydrogen peroxide (H_2O_2) placed inside a larger plastic bottle containing a solution of phenyl oxalate ester. When the light stick is shaken, the locked glass bottle will open so that the phenyl oxalate ester solution inside will mix with the H_2O_2 solution in the plastic bottle and in an instant will begin to emit light. This event is also referred to as "chemiluminescence". However, the strength of the light beam produced will be different under different conditions. Light stick A shows a faint beam of light when immersed in cold water, while light stick B shows a bright beam of light when immersed in hot water.

If a music concert is held in two different seasons (summer and winter), on which season will the light stick light up brighter? Write your argument clearly!

Figure 3. *Sample RRAT Questions*

Data Analysis

Assessment of scientific argumentation was conducted following the framework developed by Cetin (2013), which classified argumentation into different levels. A score of 1 was assigned to responses consisting solely of basic claims, while a score of 2 was given when answers included both claims and data components. A score of 3 indicated answers containing claims, data, warrants, and backing, and a score of 4 was awarded when responses consisted of claims, data, warrants, backing, and qualifiers. The assessment of students' argumentations were carried out by two persons namely the researcher and a chemistry teacher in the public high school in Malang, Indonesia. The equality of the appraisal results of the assessment by both persons were good with the Kappa value of 0.787 (p<0.05). Further details regarding the levels of scientific argumentation were shown in Table 2.

Table 2. *Description of Scientific Argument Ability Levels (Cetin, 2013)*

Category	*Description*
Level 1	The argument contains only *a simple* claim
Level 2	The argument contains *claims*, data, and/or *warrants* a. Argument comprises only *claims* and data b. Argument includes *claims* and *warrants* c. Argument contains *claims*, data, and *warrants*
Level 3	The argument contains *claims*, data/*warrants*, *backing* or *qualifiers* a. Argument incorporates *claims*, data, and *backing* b. Argument comprises *claims*, *warrants*, and *backing* c. Argument contains *claims*, *data*, and *qualifiers* d. Argument consists of *claims*, *warrants*, and *qualifiers* e. Argument includes *claims*, *warrants*, and *qualifiers* f. Argument consists *claims*, data, *warrant*, and *qualifier*
Level 4	The argument comprises *claims*, data/*warrant*, *backing*, and *qualifier* a. Argument comprises *claims*, data, *backings*, and *qualifiers* b. Argument contains *claims*, *warrant, backing*, and *qualifier* c. Argument includes *claims*, data, *warrant*, *backing*, and *qualifier*

The total scores for all student responses were computed, and the percentage of scientific argumentation results was calculated using the following formula:

$$\% \text{ The results of students' scientific arguments} = \frac{\text{Number of scores obtained}}{\text{Maximum score}} \text{ x } 100\%$$

The results of calculating the percentage of students' scientific argumentation skills were then classified into several categories as in Table 3.

Table 3. *Criteria for Scientific Argumentation Skills*

Percentage	*Category*
0-20%	Very low
20-40%	Low
40-60%	Enough
60-80%	High
80-100%	Very high

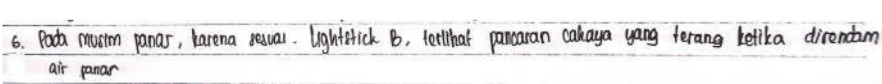
The improvement in scientific argumentation skills was statistically tested using One Way ANOVA test and Post-hoc Scheffe test to identify differences among the classes. To assess the impact of learning strategies on scientific argumentation skills analyses was carried out (Hake, 1998).

Results

Students' responses to RRAT were categorized according to the level of argumentation in the framework. The following results served as samples of students' scientific argumentation at four different levels.

Scientific Argumentation Level 1

At Level 1 students' scientific arguments consisted of simple claims unsupported by other argumentation components. Level 1 scientific argumentation indicated that students could argue but their arguments remained weak due to a lack of supporting data. ELS class students achieved Level 1 scientific argumentation at a rate of 15.63%. On the other hand, the MLS-PDCA SSI and MLS-PDCA classes achieved at least Level 2 (indicating better quality of scientific argumentation). An example of Level 1 scientific argumentation was shown in Figure 4.

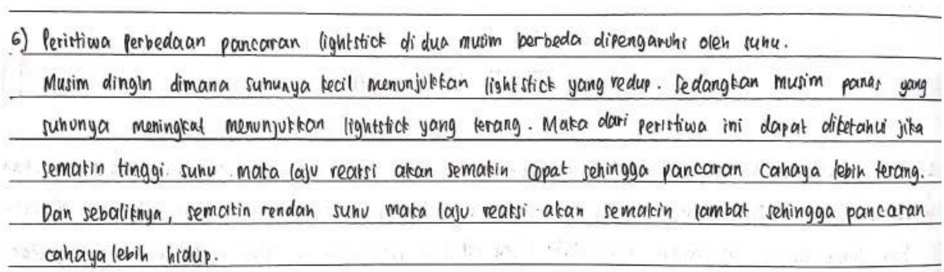


In the summer, Lightstick B has a visible bright glow when immersed in hot water.

Figure 4. *Example of Level 1 Scientific Argumentation*

Scientific Argumentation Level 2

Level 2 scientific arguments contained components of claims, data, and/or warrants. The claims put forth were substantiated with valid data. In the MLS-PDCA SSI and MLS-PDCA classes 6.25% and 15.63% of students reached Level 2 respectively, while 37.50% in the ELS class attained this level. An example of scientific argumentation at Level 2 could be seen in Figure 5.

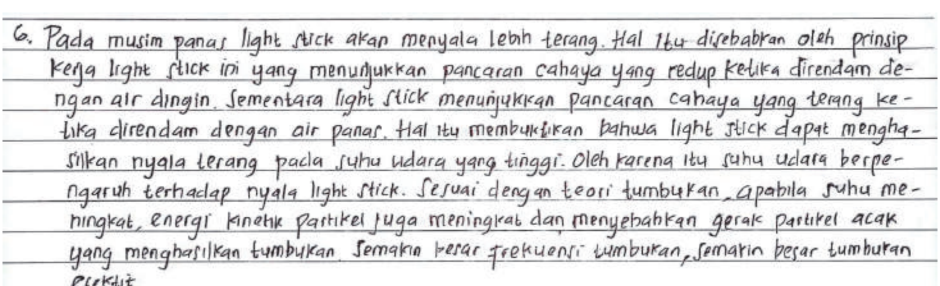

6) Peristiwa perbedaan pancaran lightstick di dua musim berbeda dipengaruhi oleh suhu. Musim dingin dimana suhunya kecil menunjukkan lightstick yang redup. Sedangkan musim panas yang suhunya meningkat menunjukkan lightstick yang terang. Maka dari peristiwa ini dapat diketahui jika semakin tinggi suhu maka laju reaksi akan semakin cepat sehingga pancaran cahaya lebih terang. Dan sebaliknya, semakin rendah suhu maka laju reaksi akan semakin lambat sehingga pancaran cahaya lebih hidup.

The difference in lightstick emission between seasons was influenced by temperature. During winter, when temperatures were low lightsticks emitted dim light. While in summer, when temperatures rose, they emitted bright light. Therefore, this event indicated that higher temperatures led to faster reactions and brighter light beams, while lower temperatures resulted in slower reaction rates and dimmer light beams.

Figure 5. *Example of Level 2 Scientific Argumentation*

Scientific Argumentation Level 3

Students at Level 3 developed scientific arguments comprising claims, data, warrants, backing, and qualifiers. These arguments included warrants that connected claims and data, and backing consisted of supporting theories that strengthened the warrants to validate the information. In the MLS-PDCA SSI class 28.13% of students reached scientific argumentation Level 3 (most of the students (65.63%) are at level 4), while the MLS-PDCA and ELS classes had 59.38% and 43.75%. respectively. A sample of Level 3 scientific argumentation could be seen in Figure 6.


6. Pada musim panas light stick akan menyala lebih terang. Hal itu disebabkan oleh prinsip kerja light stick ini yang menunjukkan pancaran cahaya yang redup ketika direndam dengan air dingin. Sementara light stick menunjukkan pancaran cahaya yang terang ketika direndam dengan air panas. Hal itu membuktikan bahwa light stick dapat menghasilkan nyala terang pada suhu udara yang tinggi. Oleh karena itu suhu udara berpengaruh terhadap nyala light stick. Sesuai dengan teori tumbukan, apabila suhu meningkat, energi kinetik partikel juga meningkat dan menyebabkan gerak partikel acak yang menghasilkan tumbukan. Semakin besar frekuensi tumbukan, semakin besar tumbukan efektif.

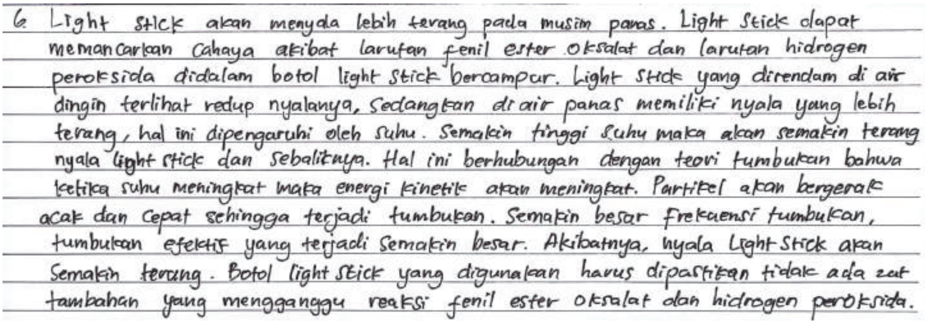
During the summer, lightsticks emitted a brighter glow which resulted from the lightstick's operation. Moreover, when immersed in cold water it emitted a faint glow but produced a bright beam of light in hot water. This indicated the capacity of lightstick to generate a bright flame under higher air temperatures. According to the collision theory, the increase in temperature led to heightened kinetic energy among random particles, resulting in more frequent and effective collisions.

Figure 6. *Example of Level 3 Scientific Argumentation*

Scientific Argumentation Level 4

Students at Level 4 showed comprehensive scientific argumentation, including claims, data, warrants, backing, and qualifiers. The analysis results revealed that within the MLS-PDCA SSI class, 65.63% of students reached Level 4 in their argumentation skills.

This showed the effectiveness of integrating the SSI context into the learning process for improving students' scientific argumentation abilities. In comparison, only 25% of MLS-PDCA class students and a mere 3.13% of ELS achieved Level 4 proficiency. An example of Level 4 scientific argumentation was shown in Figure 7. The MLS-PDCA SSI class achieved the highest average score for scientific argumentation skills compared to the MLS-PDCA and ELS classes.


6. Light stick akan menyala lebih terang pada musim panas. Light Stick dapat memancarkan Cahaya akibat larutan fenil ester oksalat dan larutan hidrogen peroksida didalam botol light stick bercampur. Light Stick yang direndam di air dingin terlihat redup nyalanya, Sedangkan di air panas memiliki nyala yang lebih terang, hal ini dipengaruhi oleh suhu. Semakin tinggi suhu maka akan semakin terang nyala light stick dan sebaliknya. Hal ini berhubungan dengan teori tumbukan bahwa ketika suhu meningkat maka energi kinetik akan meningkat. Partikel akan bergerak acak dan cepat sehingga terjadi tumbukan. Semakin besar frekuensi tumbukan, tumbukan efektif yang terjadi semakin besar. Akibatnya, nyala Light Stick akan Semakin terang. Botol light stick yang digunakan harus dipastikan tidak ada zat tambahan yang mengganggu reaksi fenil ester oksalat dan hidrogen peroksida.

In summer, lightsticks burned more brightly and also emitted light through a combination of phenyl ester oxalate and hydrogen peroxide solutions. Submersion in cold water dimmed its glow, but hot water made it burn more brightly due to temperature's influence. Higher temperatures equated to a more intense flame, and the reverse was true for lower temperatures. This phenomenon was in accordance with the collision theory, where increased temperature led to greater kinetic energy. Particles moved more randomly and rapidly, increasing the frequency of collisions, thereby leading to a brighter flame. It was crucial to ensure that the lightstick container did not contain any additives that could disrupt the reaction between phenyl ester oxalate and hydrogen peroxide.

Figure 7. *Example of Level 4 Scientific Argumentation*

Assessment the normality of the initial skills (pre-test) and final ability (post-test) data regarding scientific argumentation skills were conducted by the Kolmogorov-Smirnov test, as shown in Appendix 1 (Table A1). Based on Table A1, it was evident that the data for the pre-test and post-test scientific argumentation skills of students in all classes followed a normal distribution. The homogeneity test results for pre-test and post-test scientific argumentation skills in MLS-PDCA SSI, MLS-PDCA, and ELS classes were shown in Appendix 1 (Table A2).

The data in Table A2 showed that the pre-test and post-test scientific argumentation skills of students in all classes were categorized as homogeneous. The pre-test comparison of scientific argumentation skills was conducted using parametric statistics with a One-Way ANOVA Test. The findings related to differences in pre-test scientific argumentation skills were shown in Table 4.

Table 4. *One-Way ANOVA Test Pre-test of Scientific Argumentation Ability*

	Sum of Squares	df	*Mean Square*	F	*Sig.*
Between-group	2,438	2	1,219	0,015	0,985
Within group	7463,942	93	80,257		
Total	7466,379	95			

Table 4 showed that there were no significant differences in the pre-test scores of scientific argumentation skills between the experimental class and the control classes (p = 0.985, *sig.* > 0.05). The results of the One-Way ANOVA Test for post-test data on scientific argumentation skills were in Table 5.

Table 5. *One-Way ANOVA Post-test of Scientific Argumentation Ability*

	Sum of Squares	df	*Mean Square*	F	*Sig.*
Between groups	4785,941	2	2392,970	31,574	0,000
Within group	7048,477	93	75,790		
Total	11834,418	95			

Based on the data in Table 5, differences in post-test scientific argumentation skills were observed among the MLS-PDCA SSI, MLS-PDCA, and ELS classes. The Scheffe test results for post-test data on scientific argumentation skills were shown in Table 6.

Table 6. *Scheffe Test of Students' Scientific Argumentation Skills*

(I) Strategy	*(J) Strategy*	*Mean Difference (I-J)*	*Std. Error*	*Sig.*	*95% Confidence Interval*	
					Lower Bound	*Upper Bound*
MLS-PDCA SSI	MLS-PDCA	7.71375*	2.34192	.006	1.8878	13.5397
	ELS	19.43313*	2.34192	.000	13.6071	25.2591
MLS-PDCA	MLS-PDCA SSI	-7.71375*	2.34192	.006	-13.5397	-1.8878
	ELS	11.71938*	2.34192	.000	5.8934	17.5454
ELS	MLS-PDCA SSI	-19.43313*	2.34192	.000	-25.2591	-13.6071

From Table 6, the following were deduced:

1) There were significant differences (*sig.*<0.05) in the scientific argumentation skills of students taught with the MLS-PDCA SSI strategy compared to the MLS-PDCA strategy.

2) Differences existed (*sig.*<0.05) in the scientific argumentation skills of students taught with MLS-PDCA SSI strategy compared to the ELS strategy.

3) Differences were observed (*sig.*<0.05) in the scientific argumentation skills of students taught with the MLS-PDCA strategy compared to the ELS strategy.

Table 6 also showed that the MLS-PDCA SSI class had average scientific argumentation proficiency difference scores of 7.714 and 19.433 points higher than students taught with MLS-PDCA and ELS, respectively. In addition, students in the MLS-PDCA classes had an average difference score of 11.719 points higher than those in the ELS classes.

The impact of learning strategies on students' scientific argumentation skills was seen through the *N-gain* in each class. *N-gain* was used to determine the effectiveness of various strategies (MLS-PDCA SSI, MLS-PDCA, and ELS). Table 7 showed that the *N-gain* in scientific argumentation skills from all three classes indicated an improved understanding of learning outcomes.

Table 7. *N-gain Students' Scientific Argumentation Skills*

Skor	MLS-PDCA SSI Class			MLS-PDCA Class			ELS Class		
	Pre-test	Post-test	N-gain	Pre-test	Post-test	N-gain	Pre-test	Post-test	N-gain
Average	27.44	87.79	0.83	27.83	80.08	0.72	27.64	68.36	0.56
Score maximum	43.75	100		43.75	96.88		43.75	87.50	
Score minimum	15.63	68.75		12.50	59.38		15.63	53.13	
Number of students (N)	32	32		32	32		32	32	

Discussion

Assessing metacognitive knowledge and skills improved self-awareness when constructing scientific explanations, especially regarding components namely claims, data, and explanations (Wang, 2015). High levels of metacognitive skills facilitated problem-solving, critical thinking, and creativity in forming well-structured arguments.

The analysis of scientific argumentation skills was based on the argumentation assessment framework developed by Cetin (2013). In the MLS-PDCA SSI class students achieved the highest level of scientific argumentation (level 4), surpassing students in the MLS-PDCA and ELS classes. This result was consistent with previous studies suggesting that introducing SSI context in learning helped students develop and achieve the highest level of scientific argumentation (Dawson & Venville, 2010).

Scientific argumentation played a crucial role in communication within the field of science, helping students comprehend concepts, construct scientific explanations, and develop scientific literacy (Hsu et al., 2015). In this study, Toulmin's argumentation framework was utilized and it classified scientific arguments into four levels (1-4), comprises claims, data, warrants, backing, qualifiers, and rebuttals (Cetin, 2013). Incorporating scientific argumentation into the learning process enabled students to actively engage in learning and practice critical as well as creative thinking skills, essential in the 21st century (Demircioglu et al., 2022). Moreover, scientific argumentation skills equipped students with the ability to make decisions and operate as scientists (Sparks et al., 2022). This implied that contemporary science education should prioritize the development of students' scientific argumentation skills.

MLS-PDCA SSI learning combines the PDCA metacognitive learning strategy with the SSI context to help students develop scientific argumentation skills through structured learning activities. In the "preparation" phase, students define their learning objectives, prior knowledge, essential concepts, and questions related to new material not yet understood which they record in learning journals. During this stage, the teacher evaluates students' prior knowledge before commencing the learning process. Assessing prior knowledge serves as a reference and aids in understanding cognitive abilities and self-assessment (Jaleel & Premachandran, 2016). Teachers can utilize this knowledge of students' prior understanding to predict the development of scientific argumentation skills and provide necessary support to improve metacognitive awareness. A better quality of prior knowledge showed how effectively and swiftly students can engage in the learning activities.

The "doing" phase of the PDCA metacognitive learning strategy was designed to improve understanding of concepts and comprehension through discussions, Q&A sessions, presentations, debates, and hands-on activities (Parlan et al., 2018). Engaging in discussions, presentations, Q&A sessions, and debates during that stage provided valuable learning experiences and assisted in the development of scientific argumentation skills. The introduction of SSI context in the learning process encouraged students to think critically and creatively, enabling them to propose solutions to social issues related to the subject matter (Lopez-Fernandez et al., 2022). The integration of the SSI context into chemistry learning helped nurture metacognitive abilities that were crucial in the problem-solving process (Ozturk, 2017). The controversial inclusion of SSI contexts in metacognitive learning also played a critical role in sharpening students' scientific argumentation skills. The SSI context tended to stimulate motivation and interest, making students more active in group discussions. Some of the SSI contexts explored in this study included (1) the beauty and impact of fireworks on health, (2) rocket missions to Mars, (3) chlorine radicals and their role in ozone layer depletion, and (4) the effects of alcohol on health. The SSI context was introduced during the "preparation" phase of each learning activity. The scientific argumentation process incorporated presenting claims, which were supported by crucial components of scientific argumentation, including data, warrants, backing, qualifiers, and rebuttal. This included mutually challenging and refining claims to shape students into well-structured and logically sound arguments. This result was in line with the discovery of Minata et al. (2022) which described how the introduction of context in learning empowered students to engage in scientific debates and provide explanations for phenomena. Furthermore, the results of this study were reinforced by previous explorations indicating that learning comprising SSI context enhanced students' scientific argumentation skills by encouraging them to express their opinions, provide scientific evidence, and offer reasoning or explanations that supported their scientific evidence (Dawson & Venville, 2010).

The process of training scientific argumentation skills unfolded in stages within the MLS-PDCA SSI and MLS-PDCA strategies. However, in the ELS class argumentation was not directly taught but was developed through group discussions. In the MLS-PDCA SSI class, argumentation skills were practiced during the "preparing" stage. Integrating the SSI context presented in the learning MLS-PDCA class students improved their scientific argumentation skills during the "doing" stage, while ELS class refined scientific argumentation skills through group discussion sessions.

The results of the study showed that most of the students (65.63%) of the MLS-PDCA SSI class managed to achieve the argument at level 4. This shows that the SSI context applied to learning is able to train students to develop the ability to construct their arguments.

Conclusion

In conclusion, the analysis and discussion showed that (1) Students taught with MLS-PDCA SSI demonstrated a more substantial improvement in scientific argumentation skills compared to those instructed with MLS-PDCA and ELS. (2) The implementation of MLS-PDCA SSI effectively improved scientific argumentation skills. Metacognitive strategies facilitate students to use their prior knowledge to construct new understandings so that a deeper understanding is obtained and monitoring their understanding. A student who has good understanding will be able to compile better scientific arguments as well.

The use of socioscientific issue as a learning context in chemistry increases students' motivation and curiosity. The use of socioscientific issues also makes the chemistry close to their everyday life. Therefore, the students are happier and more motivated to learn of chemistry.

To implement MLS-PDCA SSI strategy teachers need to choose socioscientific issue that are relevant to the material to be learned. MLS-PDCA SSI strategy was perfect for teaching materials related to everyday life and practical applications.

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Appendix A. Normality and Homogeneity Test *Data* of Students' Scientific Argumentation Skills

Table A1. *Data on Pre-test and Post-test Normality Test Results of Students' Scientific Argumentation Skills*

Class	*Assessment*	*N*	*Average*	*SD*	*Sig.*	*Information*
MLS-PDCA SSI	Pre-test	32	27.44	9.11	0.097	Normal
	Post-test		87.79	7.54	0.108	Normal
MLS-PDCA	Pre-test	32	27.83	8.45	0.200	Normal
	Post-test		80.08	10.46	0.197	Normal
ELS	Pre-test	32	27.63	9.29	0.107	Normal
	Post-test		68.36	9.84	0.170	Normal

Table A2. *Data on Pre-test and Post-test Homogeneity Test Results of Students' Scientific Argumentation Skills*

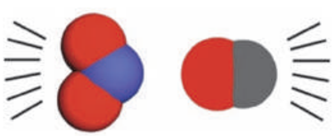
	α	*Sig. (2-tailed)*	*Criteria*	*Information*
Pre-test	0.05	0.352	α < *Sig.*	Homogen
Post-test	0.05	0.063	α < *Sig.*	Homogen

Appendix B. An example item of an argumentation test
Air Pollution

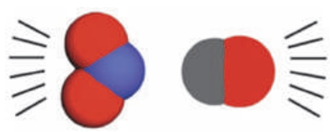
Air pollution has become a global problem. About 92% of the world's population lives in areas with air pollution above the threshold set by WHO. Some air pollutants such as SO_2. NO_x. and CO from the burning of fossil fuels occur inside motor vehicle engines. To reduce the emissions of air pollutants. scientists built a *catalytic converter*. a device installed between the engine and exhaust of a motor vehicle. The device contains a catalyst for the catalytic reaction of toxic exhaust gases into nontoxic compounds. In the air carbon monoxide gas can react with nitrogen dioxide endothermically at temperatures above 225°C with the following equation:

$$CO(g) + NO_2(g) \rightarrow CO_2(g) + NO(g).$$

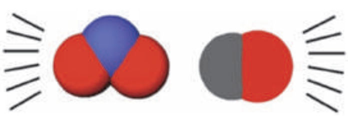
The following is a submicroscopic representation of the possibility of collisions between reagent particles.



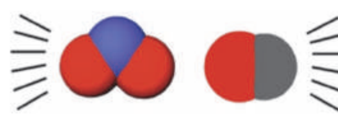
Pic .1



Pic. 2



Pic. 3



Pic. 4

Information:

Based on the description of the information above. Which image can produce an effective collision? State your argument!