Bioedukasi: Jurnal Pendidikan Biologi Vol. 19(2) 2026 | 182-193

UNIVERSITAS SEBELAS MARET
BIOEDUKASI: JURNAL PENDIDIKAN BIOLOGI
https://jurnal.uns.ac.id/bioedukasi
1693-265X (Print) | 2549-0605 (Online)

The Effect of STEM-Shinka-Integrated Student Worksheets on Critical Thinking Skills in Environmental Topics

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Submission : 01/07/2026

Revision : 07/08/2026

Accepted : 30/08/2026

ABSTRACT

The critical thinking skills of Indonesian students are still relatively low, as shown by several research findings. One of the factors causing this is teaching materials and student worksheets that have not been optimally designed. Previous studies on STEM-based worksheets indicate that implementation is often incomplete, reflecting STEM aspects through isolated questions rather than systematic learning syntax. Meanwhile, the Shinka structure emphasizes the gradual development of students' thinking through elements such as thinking models' presentation, interaction columns, and reflection revision, aligning with the STEM approach in solving real-world problems. This study aims to determine the effect of using STEM-Shinka worksheets on students' critical thinking skills (CTS) on Environmental topic. This study uses a quasi-experimental method with a pretest-posttest control group design, involving two classes in Grade 10. Data were collected through CTS instruments in the form of essay questions and analyzed using ANCOVA. Results showed that the experimental class achieved a higher posttest mean than the control class, with the ANCOVA test yielding a significance value of 0.009 (<0.05) and an effect size ($\eta^2 p$) of 0.100 (medium effect), indicating a significant effect of the use of STEM-Shinka worksheets on students' CTS. This effect is due to the alignment between STEM stages and CTS aspects and Shinka structure's role in helping students follow a clearer reasoning flow while enhancing interaction and collaboration. Further research is recommended to examine different materials or grade levels over a longer duration to confirm the effectiveness of STEM-Shinka worksheets in learning contexts.

Keywords: Student Worksheets, STEM, Shinka Approach, Critical Thinking Skills

Introduction

Critical thinking skills are one of the key skills in the context of 21st century skills. These skills involve cognitive skills, such as the skills of analyzing and interpreting information, identifying patterns and relationships, evaluating arguments, and drawing logical conclusions (Thornhill-Miller et al., 2023). It also involves a mindset characterized by an open-minded approach, curiosity, and skepticism in the problem-solving and decision-making process (Dad & Akbar, 2023). The development of critical thinking skills is important because it allows students to make informed decisions, solve problems effectively, and think creatively (Puspitasari et al., 2023).

Despite its importance, students' critical thinking skills in Indonesia remain persistently low, as reflected in evidence from various research. Research by Prasetya and Nofiana (2025) shows that the average percentage of students' critical thinking skills is only 45.6% (medium category), the highest percentage in the aspect of providing further explanations is 57.3% and the lowest average percentage in the aspect of simple explanations is 41.2%. Similarly, Pujiastuti (2023) tested students' critical thinking skills using essay questions showing the results of indicators that were in the undeveloped category. Comparable research was reported by Lasmana and Idris (2020), showing that students' critical thinking skills in biology learning are at a percentage of 75% included in the poor category.

This condition aligns with the results of the 2022 Programme for International Student Assessment (PISA), which shows that Indonesian students' scientific literacy remains relatively low. Since PISA's framework requires students to analyze, evaluate, and reason through scientific problems, which are core components of critical thinking, students' PISA performance can be considered a broader indicator of their critical thinking skills. Indonesia ranks 71st out of 81 countries with an average score of 383, far below the international average score of 485. The majority of Indonesian students are at low levels, namely levels 1a, 1b, and 2, with dominance at level 1a. Based on the PISA framework, level 1a indicates that students have limited scientific skills and basic skills. This indicates that Indonesian students have difficulties in understanding scientific concepts and processes and are unable to apply scientific skills to solve conceptual problems.

The low critical thinking skills of students in Indonesia indicate that the learning methods and models used are not fully in accordance with the characteristics of science learning (Ramadhan & Ijirana, 2023). Science learning in schools still focuses on the transfer of knowledge in the form of facts, laws and theories that students must memorize. This condition ignores the development of science process skills and is still teacher-centered, so it does not encourage critical thinking and problem-solving skills among students (Putri et al., 2025). Addressing this gap requires the availability of teaching materials specifically design to actively engage students in the reasoning process, rather than materials that merely support content delivery.

The teaching materials used in learning are limited to textbooks, while the student worksheets used have not implemented appropriate learning measures. As a result, students have difficulty in practicing critical thinking skills. Research by Chutami and Suhartini (2021) supported by Kosim et al. (2023) states that the use of well-designed worksheets can make the learning process more effective and efficient. Therefore, it is necessary to develop teaching materials combined with appropriate learning models in order to be able to stimulate students' critical thinking skills. The use of student worksheets with the right learning model is expected to help teachers carry out learning more effectively and encourage student activity in the learning process (Nurjaya & Wulandari, 2023).

STEM is a learning approach that integrates science, technology, engineering, and mathematics to collect, analyze, and solve problems that occur, as well as the existence of relationships between one problem and another (Nugraha et al., 2024). Within this approach, the Engineering Design Process (EDP) functions as the practical framework through which students engage in structured classroom learning (Asimakopoulos et al., 2024). Research by Lestari et al. (2018) shows that the application of worksheets by integrating STEM elements can develop students' critical thinking skills. In addition, Silvia and Simatupang (2020) stated that the collaboration of teaching materials with the STEM approach can increase the effectiveness of the teaching materials used.

However, the results of studies on several STEM-based worksheets from previous studies show that the application of STEM has not been fully applied in the worksheet structure. STEM is still positioned as a limited multidisciplinary approach in the learning process. Most of the STEM content is only in the form of questions or instructions that reflect aspects of science, technology, engineering, and mathematics without using the stages of STEM learning in a systematic way. Based on these problems, innovation is needed in the learning process, one of which is through the development of STEM-based student worksheets.

Beyond the STEM approach, science learning practices in Japan can be used as a relevant reference to overcome science learning problems in Indonesia. Student worksheets in Japan generally integrate three main components, namely (1) knowledge and skills, (2) thinking, assessing and expressiveness, and (3) independent learning attitudes (Nakayama et al., 2024). The worksheets developed in this study adapt the Shinka structure (development or evolution of thought), which emphasizes the gradual development process of students' thinking. Aramori et al. (2025) developed a worksheet called Shinka Sheet, which contains the presentation of thinking models, trigger questions, interaction columns, comments between students, reflection, and revision of students' thinking that has been proven to be able to improve students' critical thinking skills. This structure has been shown to improve students' critical thinking skills and aligns with the STEM approach that emphasis on solving real-world problems through scientific evidence and reflective thinking.

The collaboration between the STEM approach and the characteristics of Shinka worksheets is expected to improve critical thinking skills among students in Indonesia because the two address complementary gaps. STEM provides the problem-solving structure through which reasoning is exercised, while Shinka's stepwise scaffolding provides guided support to build student reasoning skills. The material developed through STEM-based worksheets and Shinka's approach is Environmental topic. Sado et al., (2020) explain that environmental topic is effective in practicing critical thinking skills because they are directly related to the reality of life. The problems used in learning are close to the environment around students so as to reduce misconceptions and create ideal and meaningful learning (Nurahman & Susantini, 2022). Therefore, this research aims to determine the effect of the use of using STEM worksheets integrated with the Shinka Approach on students' critical thinking skills. Writing STEM-Shinka worksheets refers to STEM worksheets integrated with the Shinka Approach.

Methods

This study is a quasi-experiment research with a pretest-posttest control group design which aims to determine the effect of using STEM-Shinka worksheets on students' critical thinking skills on Environmental topic. The population in this study consisted of grade 10 students at SMA Batik 1 Surakarta, comprising 11 classes with a total of 366 students. From this population, a sample of two classes was selected through cluster random sampling. Prior to randomization, normality and homogeneity tests were conducted using the Shapiro-Wilk test and Levene's test, respectively, revealing that the data were not normally distributed. A non-parametric Kruskal-Wallis test was therefore applied, yielding a significant result (Sig. 0.001 < 0.05) indicating a significant difference among the classes. A post-hoc pairwise comparison test was subsequently conducted to identify two classes with no significant difference in initial ability. The result showed that the selected pair of classes had a Sig. value > 0.05 on the pairwise comparison test, indicating no significant difference in initial ability between them.

The experimental class (E) was given the STEM-Shinka worksheet treatment, while the control class (C) was given a conventional worksheet. Both classes were taught using STEM with the Engineering Design Process (EDP) as the practical framework for the learning model. The intervention was implemented twice, covering environmental topics with two different sub-topics, namely water pollution and air pollution. This study focuses on the effect of the worksheets on students' critical thinking skills. Each class consisted of 34 students aged 15–16 years, with 16 male and 18 female students in the experimental class, and 18 male and 16 female students in the control class. Students in both classes were assumed to have relatively homogeneous socioeconomic backgrounds, considering that the research was carried out in private schools with similar student characteristics.

Data were collected through pretest and posttest measures of students' critical thinking skills. The instrument used the critical thinking framework of Ennis, (1996), which consists of five indicators with 12 sub-indicators. These 12 sub-indicators formed the basis for the 12 essay questions on environmental topics used in the instrument. The aspects of critical thinking skills are elementary clarification, building basic support, inference, making advanced clarification, and strategy and tactics. Before being used in research, test questions are first tested for validity and reliability. The validity test, using the Pearson product-moment correlation, showed that all items were valid, with r values ranging from 0.417 to 0.820 > r table 0.1707. The reliability test, using Cronbach's Alpha, yielded a coefficient of 0.876 > 0.1707, indicating high reliability. Scores for critical thinking were assigned on a scale of 1-4 per item, with the total score calculated as the sum of item scores divided by the maximum possible score (48), multiplied by 100.

The statistical test used in this study is the ANCOVA (Analysis of Covariance) test. The ANCOVA test is a statistical technique that combines regression analysis and variance analysis to determine the effect of treatment by controlling for covariate variables (Jaya, 2019). Before the ANCOVA test, assumption tests were conducted, including normality, homogeneity, linearity, and homogeneity of regression slopes tests. In this study, the pretest value was used as a controlled covariate to reduce variance error. A significance value (Sig.) below 0.05 indicates a significant effect of the use of STEM-Shinka worksheets on students' critical thinking skills on Environmental topic. In contrast, a value above 0.05 indicates no significant effect. In addition to the p-value, effect size (η^2p), confidence interval, and adjusted means were also used to interpret the data. The effect size was interpreted using Cohen's (2013) criteria, where $\eta^2p \approx 0.01$ indicates a small effect, $\eta^2p \approx 0.06$ indicates a medium effect, and $\eta^2p \approx 0.14$ indicates large effect.

Results and Discussion

The critical thinking skills of the control class and the experimental class were measured through a pretest and posttest consisting of 12 questions. Descriptions of students' pretest and posttest critical thinking skills are presented in Table 1. Based on the table, the increase in the average value of critical thinking skills of students in the experimental class was higher than in the control class. Figure 1(a) is a visualization of the distribution of data in the form of a scatter plot that shows the relationship between pretest and posttest in the experimental class and the control class. Based on the graph, there are two lines with a positive slope, which means that there is a linear relationship between pretest and posttest scores; namely, the higher the student's pretest score, the higher the posttest score obtained.

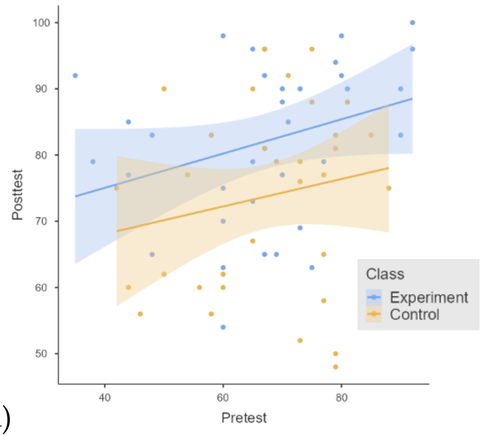
Table 1. Description of critical thinking skills data

Description	Pretest		Post-test	
	Control Class	Experimental Class	Control Class	Experimental Class
N	34	34	34	34
Mean	67.2	67.2	73.7	82.1
Std. Deviation	12.1	14.7	13.9	12.4
Minimum	42	35	48	54
Maximum	88	92	96	100
Range	46	57	48	46

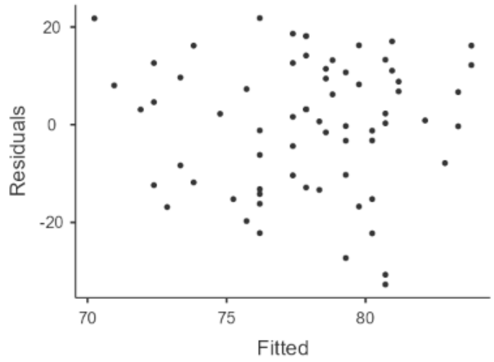
The N-gain calculation showed a value of 0.41 (medium category) for the experimental class and 0.10 (low category) for the control class (Hake, 1998). This category difference shows that the increase in experimental classes with the implementation of STEM-Shinka worksheets is higher than in classes that use conventional worksheets. The conventional worksheets consisted of student identity, learning objectives, and questions organized according to the STEM aspects (Science, Technology, Engineering, and Mathematics). On the other hand, STEM-Shinka worksheets consisted of student identity, learning objectives, instructions, the STEM-EDP syntax, and Shinka structure, comprising a problem column, conversation balloons, and conclusion column. The Shinka structure was adapted into the imagine and redesign stages of the STEM-EDP framework to help guide student reasoning process.

In addition, the average data of pretest-posttest scores of each aspect of critical thinking skills in the experimental class are presented in Table 2. Based on the table, all the average scores of critical thinking skill aspects have increased. The critical thinking skills aspect that has the highest score difference is the elementary clarification aspect, with a difference of 22.30, and the strategy and tactics aspect, with a difference of 22.06. The aspect of critical thinking skills with the lowest value difference is building basic support, with a value difference of 2.94. Meanwhile, the average pretest-posttest scores of each aspect of critical thinking skills in the control class are presented in Table 2; the highest score difference, namely the advanced clarification aspect, with a difference of 11.03 and the strategy and tactics aspect, with a difference of 11.76. The aspect of critical thinking skills with the lowest value difference is inference, with a value difference of 0.25. Based on the comparison of pretest and posttest scores in the control and experimental classes, it can be seen that the experimental class has an average increase in all aspects of critical thinking skills.

The critical thinking skills data in this study met the normality assumption using the Shapiro-Wilk test, with a Sig. value > 0.05, meaning the data were normally distributed. The homogeneity test using the *Levene* test also showed a Sig. value > 0.05, indicating that the data had homogeneous variance. The linearity between the pretest and posttest scores was examined using simple linear regression (R=0.232, R2=0.054) and a residuals-fitted plot (Figure 1b). The residuals were randomly scattered around zero without forming a systematics curved pattern, supporting the assumption of linearity. The homogeneity of regression slopes assumption was tested through the interaction between class and pretest, producing a p-value of 0.832, which is not significant, indicating that the assumption of equal regression coefficients was met. As the data met the assumptions of normality, homogeneity, linearity, and homogeneity of regression slopes, the analysis proceeded to hypothesis testing using the *ANCOVA* test.



(a)



(b)

Figure 1. (a) Distribution of critical thinking skills data, (b) Residuals-fitted score plot for linearity

Table 2. Average Aspects of Critical Thinking Skills in Experimental and Control Classes

Critical Thinking Skills Indicator	Experimental Class			Control Class		
	Average pretest score	**Average post-test score**	**Value difference**	**Average pretest score**	**Average post-test score**	**Value difference**
Elementary clarification	56.13	78.43	22.30	62.75	71.32	8.58
Building basic support	91.18	94.12	2.94	72.06	75.37	3.31
Inference	72.79	83.82	11.03	71.81	72.06	0.25
Advanced clarification	63.60	77.57	13.97	64.34	75.37	11.03
Strategy and tactics	54.78	76.84	22.06	65.07	76.84	11.76

The results of the ANCOVA test on the pretest-posttest data showed F (1,65) =7.19 with a Sig. value of 0.009 (< 0.05), indicating a significant effect of the use of STEM-Shinka worksheets on students' critical thinking skills in Environmental topic. The partial eta squared (η^2p) value is 0.100. This indicates that the magnitude of the treatment effect falls into the medium effect category according to Cohen's (2013) criteria. This moderate effect may be attributed to the relatively short duration of the intervention, which was implemented only twice. The adjusted mean of the experimental group was 82.1, higher than the control group at 73.7 (Table 4). The non-overlapping confidence intervals between the two groups further support the statistical significance of the between-group difference. The relatively low standard error of 2.20, given a score range of 0-100, indicates that the mean estimates for both groups were stable and precise. These findings indicate that the implementation of STEM-Shinka worksheets consistently enhanced students' critical thinking skills compared to conventional worksheets, with a meaningful effect size within the medium category.

The application of STEM-Shinka worksheets in the experimental class has advantages compared to the application of conventional worksheets in the control class. The combination of engineering design concepts and science, technology, and mathematics learning is a hallmark of STEM learning. As students strive to learn, understand, and hone skills in Science, Technology, and Mathematics, students have the opportunity to apply the knowledge gained to design products or methods to meet their problem-solving needs in daily life (Kelley & Knowles, 2016). STEM learning in this study uses the stages of the Engineering Design Process (EDP) as a structured practical framework to accommodate STEM elements in one learning flow (Asimakopoulos et al., 2024). The worksheet structure in the experimental class applies the stages of the Engineering Design Process (EDP), which consist of defining the problem, research, imagine, plan, create, test and evaluate, redesign, and communication. This stage refers to organizing ideas to improve decision-making in order to develop high-quality solutions and products to solve problems (Bunprom et al., 2021).

Table 3. ANCOVA test result of critical thinking skills data

	df	F	*P*	η^2p	Criteria	Decision
Critical Thinking Skills	1	7.19	0.009	0.100	< 0.05	There are differences

Table 4. Adjusted means of critical thinking skill data

Class	Mean	SE	95% Confidence Interval	
			Lower	Upper
Experiment	82.1	2.20	77.7	86.5
Control	73.7	2.20	69.3	78.1

This finding is consistent with Lestari et al., (2018), who showed that STEM-integrated worksheets can develop students' critical thinking skills. In addition, Sutarto et al., (2021) found that STEM-based worksheets improved students' critical thinking skills, with the highest improvement observed in the explanation indicator (0.87), classified as high. This aligns with Indrasti and Paidi (2025), who found that a STEM-integrated project-based learning tool on the topic of environmental change was effective in improving critical thinking skills, with an n-gain of 0.70 (high category) and significant improvements across all critical thinking skill indicators, particularly the inference indicator. These findings support the notion that each stage of STEM applied in this research engages students in the systematic, evidence-based reasoning processes required for critical thinking. This study further extends that evidence to STEM-Shinka integration, which prior research has not examined.

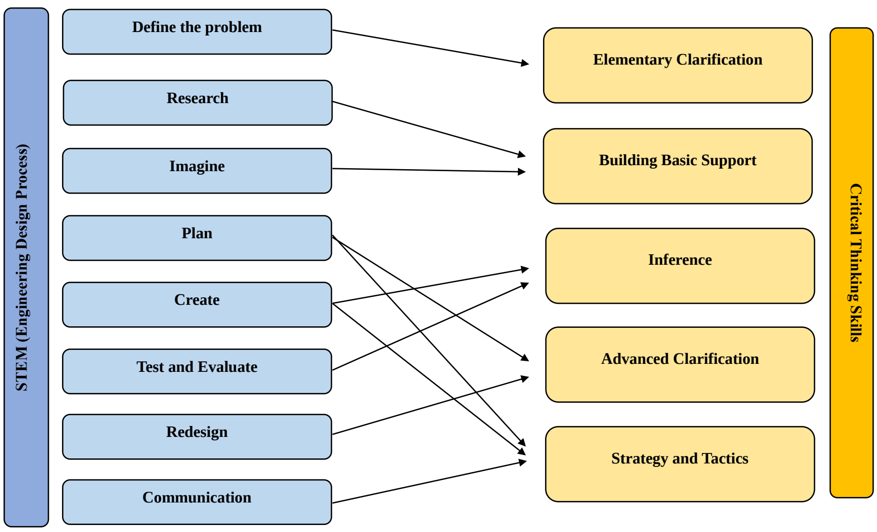


Figure 2. Relationship between STEM stages and critical thinking skill aspects

The application of STEM stages in student worksheets aligns with students' critical thinking process (Figure 2), as each STEM stage can support specific aspects of critical thinking skills. This result aligns with Yu et al. (2020), which states that STEM plays an important role in developing critical thinking skills; when students complete the STEM stages, they also develop and meet the criteria for critical thinking skills. The problem-defining stage supports the elementary clarification aspect of the process. This stage is the initial stage for students to identify and formulate the problems presented (Sapphira & Sari, 2024). The questions are formulated to show the relationship between the problem and the material studied. This process encourages students to think deeply about how to solve the problem (Mutakinati et al., 2018). The elementary clarification aspect has the highest average score difference of 22.30, showing that the defining-the-problem stage in STEM is effective in training students to formulate problems at the beginning of learning.

The research supports the building basic support aspect and imagine stages in STEM. In the research stage, students conduct research to obtain information about alternative solutions, while in the imagine stage, students develop ideas from information obtained in previous stages (Jolly, 2016). This stage aligns with the building basic support aspect, where students assess a source's credibility based on certain criteria and make observations and assess the results of those observations (Ennis, 1996). The average difference score for the building basic support aspect is very low at 2.94, indicating that the research and imaging stages did not substantially improve students' skills in this aspect. However, the pretest score for this aspect was already relatively high (91.18), with the posttest score reaching 94.12 (see Table 2), showing that students' initial ability to assess the credibility of sources and information was already quite good before the treatment.

The inference aspect increased an 11.03 in the medium category, indicating that the create, test, and evaluate stages can build students' ability to conclude. The create stage involves making a product designed beforehand. This stage takes the longest in the STEM syntax, as students focus not only on success but also on understanding the basic concepts of the discipline integrated into the project (Sapphira & Sari, 2024). The test and evaluate stage involve testing and evaluating the product. This syntax requires students to provide critical grades and link them to the initial theory so that they can draw logical conclusions (Purwaningsih et al., 2020). In addition, at this stage, students work in groups to discuss ideas, exchange ideas, try out designs, test, and decide on the results (Giri & Paily, 2020).

The plan and redesign stages support advanced clarification. This aspect shows an improvement in the moderate category, which indicates that the plan and redesign stages are effective for training advanced clarification skills. This stage involves students' argumentation to make decisions in a group. At this stage, students also think reflectively through self-regulation to assess and redesign the solutions that have been made. This self-regulation process involves rebuilding performance in ways that, according to students, are repetitive and aimed at achieving existing goals (Ghanizadeh, 2017).

The strategy and tactics aspect, with a high average score increase of 22.06, was supported by the plan, create, and communication stages. At the communication stage, students present the results to exchange information and opinions with other groups (Sapphira & Sari, 2024). The increase in value in this aspect is also influenced by the accuracy of the inference process, which is in the form of product design decisions, so that the quality of the product or solution produced at the create and communication stages is highly dependent on the determination of the reasoning process that has been built at the previous stage. This shows that the STEM stages are mutually sustainable, where the critical thinking skills formed at one stage become the basis for strengthening critical thinking skills in the next stage (Yu et al., 2020).

In addition to STEM, the adapted Shinka structure also helped improve students' critical thinking skills in the experimental class. The Shinka structure adapted in the worksheets presents a vertically arranged model or method of thinking, making it easier for students to follow the flow of reasoning. Furthermore, the structure provides space for interaction and collaboration among students, allowing them to gain new perspectives and enrich their understanding through other students' ideas (Aramori et al., 2025). This structure helps to improve students' accuracy in the conclusion process, as reflected in the worksheet design (Figure 3). Students first write down the problem, then exchange opinions about the solution ideas, evaluate the written solution ideas, and finally decide on the best idea. These findings align with Aramori et al. (2025), who reported significant improvements in three critical thinking factors—exploratory-rational thinking, multi-perspective thinking, and reflective thinking. This improvement occurred because students, through writing responses in the interaction columns and exchanging comments or questions on their group members' hypotheses, were encouraged to consider alternative viewpoints, re-examine errors, and deepen their own thinking. However, healthy skepticism did not increase significantly, suggesting that this disposition may require longer-term, repeated experience to develop.

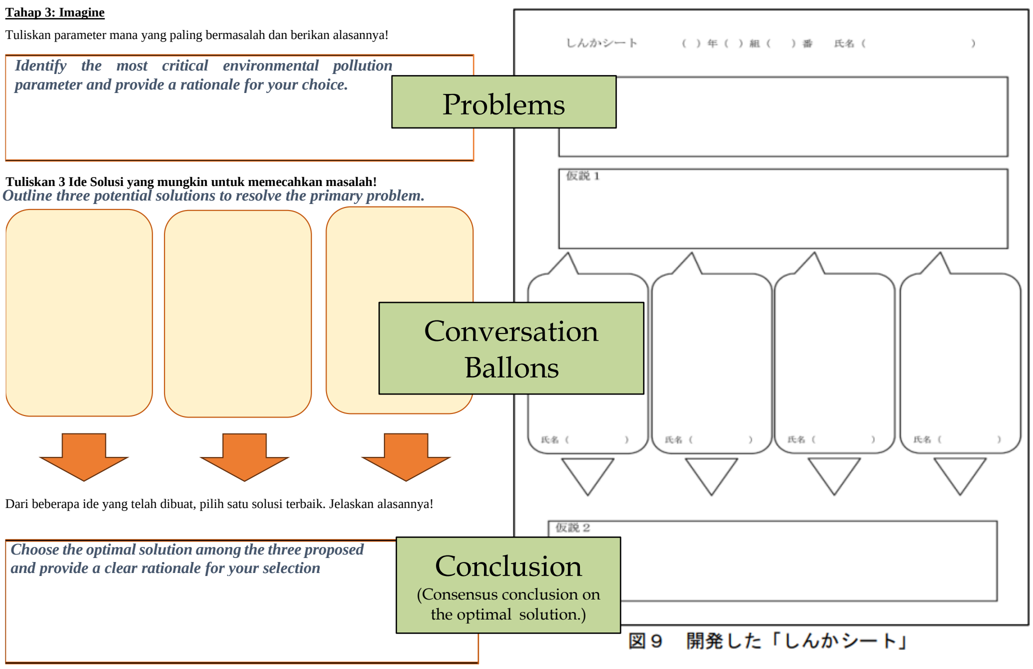


Figure 3. Adaptation of Shinka worksheets structure

The environmental topic included in this lesson is environmental pollution, focused on two sub-topics, namely water pollution and air pollution, which include causative factors, impacts on life, as well as solutions and actions to handle them (Giawa et al., 2022). Improving students' critical thinking skills in this material is expected to simultaneously increase students' concern for their environment in real terms. The measurement of critical thinking skills is important because it is an essential ability that is an indicator of learning success in achieving competency standards, as well as a form of training to face and solve real-life problems in line with the concept of science learning that prioritizes critical thinking to understand objects that are close to life (Mukti & Istiyono, 2018).

Limitations

This study has several limitations that should be acknowledged. The sample size was relatively small and limited to two classes from a single school, which may restrict the generalizability of the findings to broader populations or educational contexts. Although the sample was sufficient to demonstrate the intervention's effectiveness, future studies need a larger sample to yield more accurate results. In addition, the intervention was conducted over a relatively short duration, which may limit the extent to which the observed improvements reflect lasting rather than short-term effects.

Conclusion

Based on the results and discussion, the use of STEM-Shinka worksheets has a significant effect on students' critical thinking skills. The advantage of using STEM-Shinka worksheets in the experimental class is that the STEM stages align with the critical thinking skill indicators. Each STEM stage plays an important role in developing critical thinking skills, so when students complete the stages, they also develop and meet the criteria for critical thinking skills. In addition, Shinka's structure presents a vertical thinking model and provides space for students to interact and exchange opinions. These findings reinforce prior research on STEM worksheets while extending that evidence to STEM-Shinka integration, which has not been examined in prior research. The results show that STEM-Shinka worksheets can be an effective alternative teaching material for improving students' critical thinking skills. This study has limitations, including a relatively small sample and a short intervention duration, both of which may limit the generalizability and durability of the findings. In the next study, STEM-Shinka worksheets can be used with different materials or at different levels to test the generalizability of findings on their effectiveness. Furthermore, the study can be conducted over a longer duration to determine whether improvements in critical thinking skills are more accurate and not limited to short-term effects.

Generative AI Disclosure

The use of AI assistance was strictly limited to text translation and polishing to enhance readability. The authors retain full responsibility for the manuscript's data analysis, scientific substance, and interpretation of findings.

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