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Problem-based learning with metacognitive prompts for enhancing argumentation and critical thinking of secondary school students

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Abstract

Science education in the 21st century emphasizes the development of argumentation and critical thinking (CT) skills for socioscientific issues (SSIs), which students can also apply to any subject, such as biology. This study aimed to determine the effect of problem-based learning with metacognitive prompts (M-PBL) on students' argumentation and CT. This study employed a quasi-experimental design using a pre- and post-test non-equivalent control group. A total of 121 11th-grade students majoring in science and biology participated in this study. Participants were divided into three groups and were tested under different PBL: (1) M-PBL, 23 males and 22 females; (2) H-PBL (high-intensity problem-based learning), 15 males and 20 females; and (3) L-PBL (low-intensity problem-based learning), 26 males and 15 females. Argumentation and CT skills in M-PBL were compared with H-PBL and L-PBL. Results show that students engaging in M-PBL biology learning had higher levels of argumentation and CT skills. Students' argumentation and CT skills were significantly improved through M-PBL, and thus should be considered by teachers when restructuring lessons in a problem-solving class setting.

Keywords: argumentation, critical thinking, metacognitive prompts, problem-based learning

INTRODUCTION

An all-inclusive science education is crucial in today's knowledge-based societies to engage students in science practice, thereby promoting their scientific literacy (Vieira & Tenreiro-Vieira, 2016). All students interested in a career in science, technology, or other fields should benefit from a comprehensive science education, which includes the understanding of scientific knowledge, the development of argumentation and critical thinking (CT) skills, the identification of the role of science in society, and the contribution of science to citizenship (Valladares, 2021).

Teaching biology should be aimed at developing students' CT skills (Young et al., 2021). Interest in developing CT skills has increased in tandem with changes in the expectations placed on students. Acquiring critical thinking skills has become as important as gaining conceptual understanding. High conceptual understanding has implications for the development of CT as a "general ability" (Ab Kadir, 2018). Critical thinking requires the development of certain behaviors and skills, such as posing pertinent questions, conducting research and inquiry to find answers, being aware of controversial socioscientific issues (SSIs), and presenting evidence to support an argument (Zenker, 2018). In science education reform, changes are required in the role of students, the nature of content, assessments, and the organization of the class. This shift in educational objectives has resulted in the growing interest in CT. Additionally, it has prompted researchers and educators to explore learning processes and environments that foster students' CT (Wechsler et al., 2018).

However, a more recent perspective on scientific literacy, based on the criteria required for 21st-century lifelong skills, emphasizes the importance of improving students' argumentation and CT skills as part of a

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Contribution to the literature

- Students' critical thinking (CT) skills are improved when they are involved in evidence-based argumentation, which is one of the fundamental elements of science literacy.
- PBL with metacognitive prompts (M-PBL) is a platform for improving students' argumentation and CT skills.
- Students engaging in M-PBL biology learnings can have higher levels of argumentation and better CT.

scientific literacy framework (Valladares, 2021). Students are taught scientific literacy, which emphasizes scientific knowledge (knowledge of and about science) and its application in various contexts and situations, along with scientific ways of thinking (Yacoubian & Khishfe, 2018). Without this preparation, students are more likely to make decisions and choices that affect them and others on the basis of non-scientific preferences. Accordingly, many countries have pushed for science curricula that focus on scientific literacy, with CT and argumentation as key components (Vieira & Tenreiro-Vieira, 2016).

Jiménez-Aleixandre and Puig (2012) have investigated the contribution of argumentation in science education to the CT component. Argumentation has epistemic value because of its commitment to finding reasons and evidentiary support for opinions (García-Carmona & Acevedo-Díaz, 2018; Kuhn et al., 2017). Trends in science education emphasize argumentation as an important predictor of CT (Ariza et al., 2021). Contrastingly, argumentation involves higher-order thinking skills (Nussbaum & Sinatra, 2003), which can produce answers with valid justification (Iordanou, 2013). Thus, we examine how different problem-based learning interventions affect desired science learning outcomes.

THEORETICAL FRAMEWORK

Socioscientific Argumentation and Critical Thinking in the Science Classroom

A scientifically literate individual must possess working knowledge of scientific content, recognize how scientific knowledge is developed, and have the ability to make informed decisions about SSIs (Lobato & Zimmerman, 2019). Sadler et al. (2007) view SSIs as contentious social issues involving science that lack concrete solutions. SSIs in science classrooms provide an advantageous context for promoting civic education and teaching scientific content (Bencze et al., 2020). Exposure to SSIs is associated with an increase in students' positive attitudes toward science and an increase in their ability to comprehend people's opinions (Jho et al., 2014). Several researchers have incorporated CT and argumentation frameworks to engage students in SSIs. Scientific argumentation is crucial in the SSI classroom because each student can contribute ideas in SSI discussions (Songsil et al., 2019).

The constructivist perspective of science education highlights that argumentation is a social constructivist learning practice given its emphasis on evaluating knowledge claims. Duschl and Osborne (2002) defined argumentation as a social and collaborative process that is necessary for decision making and problem-solving skills. Thus, argumentation is addressed in a collaborative problem-solving journey for students with epistemic knowledge. Toulmin's argumentation framework has been extensively used to develop analytical models to assess the construct of students' arguments and to develop learning scripts to facilitate students' argumentation (Weng et al., 2017). Toulmin pointed out that an operational and rational argument comprises five components: claim, data, warrant, supporting argument, qualifier, and rebuttal (Erduran, 2018).

This study incorporated the components of Toulmin's argumentation, namely, evidence or data, claims, warrants or reasoning, backings, and rebuttals. Researchers have developed an SSI approach to assist students in developing realistic argumentation when making decisions about SSIs using these argumentational components (Nielsen, 2013; von der Mühlen et al., 2019). To strengthen students' understanding of argumentation, they were introduced to the following concepts prior to the commencement of the teaching program: (a) definitions and components of argument; (b) the relationships between these argumentation components; and (c) how to construct a functional argument using the five elements.

Successful teaching approaches that provide students with a PBL environment can aid students in their argumentation training on ill-structured problems (Voss, 2005). Moreover, PBL substantially helps students' argumentation learning by fostering in-depth discussions, thereby allowing students to develop evidence-based explanations and arguments (Nielsen, 2013; Yang et al., 2021). Sadler and Donnelly (2006) suggested that developing the quality and quantity of argumentation in a socioscientific context can promote scientific concept learning and CT.

Discussing, debating, and arguing about SSIs help students develop CT skills (Jafari & Meisert, 2021). In the SSI context, Yacoubian and Khishfe (2018) highlighted the alliance between argumentation and CT. According to Kim et al. (2014), argumentation is a necessary component of CT when dealing with SSIs and is required for informed decision making. For the formulated conclusion, developing a rationale for one's claims and supporting those claims with evidence in a way that is consistent with a scientist's work are critical steps in the scientific process. Two critical processes are required for the creation of knowledge. The first is research, which generates knowledge claims. The second is criticisms and arguments from members of the scientific community and the public, which allow those claims to be scrutinized and questioned. Learners can improve their scientific argumentation by engaging in this analytical process. They can also learn to filter information from various sources and determine the credibility or reasonability of the information. To be successful, learners must be able to construct and communicate persuasive scientific arguments.

Students' CT skills improve when they are involved in evidence-based argumentation, which is one of the fundamental elements of science literacy. Contemporary approaches recognize CT as a more comprehensive construct. Although it does involve fundamental reasoning components, such as inference, inductive, and deductive reasoning, CT also entails reflecting on and evaluating one's own or another's thinking (Kuhn, 2018). Critical thinking is a process that aims to generate rational and reflective choices regarding what to believe or do, which entails specific dispositions and abilities (Ennis, 2018). Whether an individual evaluates a knowledge claim or takes a position, they must try to produce a specific outcome as a result of their thinking. Following Ennis (2018), Kabataş Memiş and Çakan Akkaş (2020) claimed that learners who are in CT-promoting learning environments are those who ask additional questions and engage in additional discussions, as well as those who experience unexpected outcomes and active learning opportunities. In the development of students' CT skills, students must also be encouraged to pose their own questions and critically evaluate the evidence or ideas presented to them. Yacoubian and Khishfe (2018) argued that after being exposed to socioscientific decision making experiences, students will approach these activities critically because they will eventually be required to decide about what to believe and what to do. We define CT in the context of biological education research as recognizing assumptions, making deductions used to formulate a hypothesis, making interpretation and reasoning, making inference, and making decisions (Magno, 2010; Wechsler et al., 2018). However, in the context of different disciplines, those skills may appear to students distinctly (Thonney & Montgomery, 2019).

Using PBL with Metacognitive Prompts as a Framework for Addressing SSI

The SSI literature emphasizes the importance of selecting SSIs that are popular, debatable, appropriate for students, related to scientific knowledge, and enable open discussion among learners (Zeidler, 2014; 2015). Hancock et al. (2019) expanded this definition by defining SSIs as authentic problems that are complex and ill-structured, with undefinable solutions that require moral consideration. The units of the SSI curriculum must be carefully designed to incorporate social and scientific components and to be complex, relevant, and engaging for students. For example, water pollution is a complex issue with a broad scope, making it a critical matter for students, compelling them to advocate for decreasing polluted water. When the water pollution issue is focused on a specific context, its social complexities become apparent, making it more relevant and engaging for students. To guide students in learning SSI-based curriculum units, we used a PBL structure from the literature and teaching practice (Ghani et al., 2021; Hursen, 2021). When students are presented with real-life situations involving science and social aspects, or when they can confront SSIs, they are able to apply scientific knowledge to the personal, social, and global issues that citizens face (Xiao & Sandoval, 2017).

This paper mainly aims to discuss PBL with metacognitive prompts, which are seen as a platform for improving students' knowledge and argumentation and CT skills, through authentic scenarios, group collaboration, and self-directed learning (Dabbagh, 2019). Based on real-world problems that are significant in connecting science and other disciplines, the lessons provide significant investigation problems for developing argumentation, CT, and scientific knowledge. Metacognitive prompts integrated into the PBL help students improve their cognitive strategies and learning performance. A connection exists between metacognition and better learning performance (Mohseni et al., 2020; Syaiful et al., 2022). Students with solid metacognitive experiences tend to perform better in science. Metacognitive skills are reasonable predictors of science performance and academic achievement (Valladares, 2021). Metacognitive activities positively affect problem-solving strategies (Zhao et al., 2019). The problem-solving process includes the use of metacognition during the phases of orientation, organization, execution, and verification. PBL with metacognitive prompts (M-PBL) involves students conducting an investigation to clarify problems and reflecting on their actions through the PBL phases.

PBL with metacognitive prompts is distinguished by its ability to contribute to the development of thinking abilities and scientific knowledge (Peters, 1996). Students can even share their thoughts on what they have learned through scientific methods to deepen their understanding and improve their scientific literacy (Hernández-Ramos et al., 2021; Taber, 2015). In M-PBL, students work in pairs or groups to engage in dialogues (Chris et al., 2004). This effectively multiplies the level of engagement in reasoned discourse and argumentation, which allows metacognitive planning and reflection

(Darling-Hammond et al., 2020). We believe that fostering this reflective or metacognitive aspect of argumentation is critical for a successful teaching process. In the context of their own goal-oriented and self-directed activities, students gain extensive practice in planning and evaluation. Additionally, reflective activities encourage students to commit to and take ownership of their ideas by documenting them in writing—their arguments, evidence, counterarguments, and rebuttals—to strengthen their commitment and ownership. Thus, these written artifacts serve as a mechanism for students to understand that they are accountable for their words—that they are engaging in accountable thinking and ideas, as Tanner (2013) defines it. Students learn argumentation and CT skills during PBL scientific discussions (Kabataş Memiş & Çakan Akkaş, 2020) and have the opportunity to engage in socioscientific argumentation (Morris, 2017).

This study explores how M-PBL affected the learning performance, considering the development of argumentation and CT. We hypothesize that applying PBL with metacognitive prompts can promote students' argumentation and CT skills.

Research Question

Biology education should center on subjects that are relevant to students' lives and represent authentic and contemporary issues. Assuming that PBL and metacognition can help students improve their argumentation and CT skills, we developed PBL with a metacognitive prompt in the biology module. Thus, this study aims to address the following research questions:

1. Do differences exist in the impact of different PBLs on the mean argumentation skills?
2. Do differences exist in the impact of different PBLs on the mean CT skills?

METHODS

In this study, a quasi-experimental approach was employed using a pre- and post-test non-equivalent control group design. The learning method was used as an independent variable, whereas argumentation and CT were used as dependent variables. Otherwise, the independent variable was problem-based learning with metacognitive prompts (M-PBL), high-intensity problem-based learning (H-PBL), and (3) low-intensity problem-based learning (L-PBL). The purpose of this study is to measure the effect of the independent variable on the dependent variable, so a focus on quantitative data will be more suitable than qualitative data (Ariel et al., 2022; Drisko & Grady, 2019; Seel, 2012).

Participants

Participants were 121 11th-grade students in Indonesia majoring in science/biology. The number of participants in the research is as follows: (1) M-PBL, 23 males and 22 females; (2) H-PBL, 15 males and 20 females; and (3) L-PBL, 26 males and 15 females.

Teaching Program and Procedure

Each of the three research groups was assigned to study the same biology learning content. They participated in three-module biology: musculoskeletal, circulatory, and digestive systems. Each module is to be completed within two weeks. Before and after being taught these modules, the three research groups completed a 25-minute CT multiple-choice test followed by a 25-minute argumentation essay test.

The PBL approach was used in which students were required to submit biology-related problem-solving assignments. All three groups attended the courses for 60 minutes in each lesson session, but they were same assigned different combinations of PBL. With the help of M-PBL and H-PBL, students collaborated to solve specific problems and create data visualization. Collaborative work was equired to examine the problem and determine how to learn more about it, including finding solutions. Both groups were tasked with five-step PBL practices. (1) Presentation of ill-structured real-world problems where students were engaged in problem identification, generating ideas to inquire about, and formulating hypotheses. (2) Designing a solution to the problem. In this practice, students were informed that they need more information and skills to "dig out" solutions on their own, and with their prior knowledge and experience, students built a solid foundation of interdisciplinary knowledge and skills, as well as cognitive agility (capacity of an individual to openness and focus). (3) Group-structured inquiries. In this context, students developed self-directed learning skills to solve problems through teacher facilitation as opposed to lectures or answers. Through structured group inquiry, students develop collaboration skills and appreciate the value of multiple perspectives to address problems. (4) Develop and present artifacts and exhibit. The inquiry step was followed by the creation of artifacts and exhibits. Artifacts are more than a written report; they include videos of a problem situations and solutions. (5) Evaluation and reflection. Students developed self-assessment and self-reflection habits by repeatedly asking themselves the question.

In M-PBL, students are required to take personal and group responsibility for their learning. The M-PBL is described as an open-ended method of learning that includes the entire aspect of reflectiveness and helps students develop into good reflective thinkers as a result of their participation. In each PBL dimension, students reflected on their thinking having the "willingness to admit I/we is wrong" and the ability to be flexible where "they need to be ready to go with those things that are coming at them that are unknown and involve many risks." (Wynn et al., 2019; Wynn & Okie, 2017). At the end of the PBL, each group presented and defended their solution plan to a panel consisting of the instructor, teaching assistant, and peers. Students learned to express their opinions on how to solve problems and to differentiate between what they knew and what they did not know. M-PBL activities in detail are presented in **Appendix 1**.

The third research group used low-intensity PBL. Students in this group collaborated to answer specific questions. The group was taught the following steps: (1) reading and analyzing the content of the biological system (musculoskeletal, circulatory, and digestive), (2) question identification, (3) searching for information to answer the question, and (4) summary and reflection. The L-PBL group answered questions only by searching for information from textbooks and peer discussions.

Instruments

Multiple-choice tests were used to assess critical thinking, whereas essay tests were used to assess scientific argumentation. The researchers collaborated with two secondary school biology teachers and biologists from Universitas Negeri Malang to construct all the test items.

Toulmin's model of sound argumentation, which was used as a framework for evaluating students' argumentation, includes data, backings, warrants, evidence, claims, rebuttals, and qualifiers (Botting, 2017). The socioscientific argumentation of students was assessed using a specific rubric related to the nine dimensions of argumentation skills. Students were given a problem question which they answered using argumentation comprising claim, qualifier, evidence, identifying types of evidence, evaluation of the quality of evidence, chain and identification of reasoning (warrant), evaluation of the quality of reasoning, concerns of the student, and conclusion and explanation about the claim. The problem question and rubric for assessing student argumentation are presented in **Appendix 2**.

The CT test comprised eight items related to the five dimensions of CT: a) recognition of assumption (two items), b) deduction to formulate a hypothesis (one item), c) interpretation and reasoning (three items), d) inference (one item), and e) decision making (one item). The dimensions of CT, its definition, and samples of item states are provided in **Appendix 3**.

Content validity assesses whether all items adequately measure the content and competency of the domain of interest (Naganuma, 2017). This was evaluated in focus groups with two teachers and two biologists. How well each item's score relates to the theoretical construct used to develop the instrument is known as construct validity (Westen & Rosenthal, 2003). Pearson's correlation coefficient (Pearson's r) was used in a preliminary test to determine the construct validity of all items. The items' validity was good, with Pearson's r in the range of 0,477–0,584 ($p < 0.01$) for critical thinking and 0,679–0,848 ($p < 0.01$) for argumentation, based on a preliminary test conducted on 36 10th-grade students. The correlation coefficient is appropriate for the construct validity of an item (Matheson, 2019; Streiner et al., 2014). Cronbach's alpha for argumentation and CT instruments is above 0.8 and was declared reliable (Hair et al., 2011, 2013).

Data Collection and Analysis

The data collected in this study were scores for argumentation and CT. The data were obtained pre-test (before instruction) and post-test (after instruction). The pre- and post-test scores were meticulously corrected before being entered into Microsoft Excel. Students' argumentation test scores ranged from 0–27. The students' CT test scores ranged from 0 – 8.

Responses from three groups were obtained (M-PBL, H-PBL, and L-PBL). Based on the rubric, the scores given to these two students are as follows (**Table 1**). Question: The consumption of carbonated drinks has recently been a controversial topic revolving around public health and public policy. The consumption of sweetened carbonated drinks has been linked to diabetes, metabolic

Table 1. Answers and scores of students' arguments based on the rubric

Group	Response
M-PBL	In recent decades, consumption of sugar-sweetened beverages including soft drinks, fruit drinks, energy drinks, and vitamin water drinks has been increasing in Indonesia and across the world [Qualifier (2)]. Sugary soft drinks are composed of energy-containing sweeteners such as sucrose, high-fructose corn syrup, or fruit juice concentrates [Claim (2)]. The research evidence suggests that soft drinks consumption is associated with an increased risk of cardiovascular risk factors, metabolic syndrome, obesity, and diabetes [Evidence (3)]. I assume that the volume of beverages sold, indicative of substantial increases in sales at the population level (Type of evidence (3)]. I agree that the government prohibits the promotion of high sugar products based on location and price through law [Quality evidence evaluation (3)]. The results from the present study show that banning promotions on soft drinks would be more effective in reducing energy and sugar purchases than the soft drinks levy [Chain of reasoning (3)]. I also predicted how consumers would react to a restriction on the promotion of sweetened drinks (Student concern (3)]. The stakeholder should educate people and younger people to reduce high sugary soft drink consumption [Conclusion (3)].

Note: problem-based learning with metacognitive prompts (M-PBL), high-intensity problem-based learning (H-PBL), and (3) low-intensity problem-based learning (L-PBL).

Table 1 (continued). Answers and scores of students' arguments based on the rubric

Group	Response
H-PBL	Sweetened soft drinks consist of sweeteners such as sucrose and fructose [Claim (2)]. Research evidence suggests that soft drink consumption is associated with an increased risk of diabetes [Evidence (3)]. The results of this study indicate that the prohibition of the promotion of soft drinks will be more effective in reducing the purchase of sugar [Chain of reasoning (3)]. Thus, I agree that the government can prohibit the promotion of high sugar products through education. [Quality evidence evaluation (3)] Stakeholders must educate the public to reduce the consumption of soft drinks that are high in sugar [Conclusion (2)].
L-PBL	Sugary soft drinks contain energy-rich sugar sweeteners [Claim (1)]. Research evidence suggests that soft drink consumption increases the risk of cardiovascular disease, metabolic syndrome, obesity, and diabetes [Evidence (3)]. The results showed that the prohibition of soft drink promotion would be more effective in reducing the purchase of soft drinks [Warrant (2)]. I agree that the government prohibits the promotion of sweetened soft drink products [Conclusion (2)].

Note: problem-based learning with metacognitive prompts (M-PBL), high-intensity problem-based learning (H-PBL), and (3) low-intensity problem-based learning (L-PBL).

syndrome, cardiovascular risk factors, and other weight-related diseases. What is our argument for rejecting or accepting the soft drink promotion?

The variance and mean samples of the pre- and post-test data of the three methods were compared using analysis of covariance (ANCOVA) at a 95% confidence level to obtain a significant difference in test score increments. However, differences between the groups using ANCOVA were not identified. Thus, post hoc tests, least significant difference (LSD) method, was used to calculate the significance between three samples, enabling direct comparisons between three means from three sample groups in each dimension and total score of controlling for Type I errors.

RESULTS

During each teaching session, M-PBL and H-PBL students developed problem solutions for an issue, posed questions known as learning issues, conducted group investigations, participated in a discussion environment, integrated new knowledge into the context of the problem, and attempted to solve the problem. The students in the M-PBL actively reflected on their thinking throughout all steps of problem-solving in a goal-oriented and self-directed environment. Ultimately, they recognized that learning is a continuous process. The instructor encouraged students to participate in each teaching session, ensured that students met the appropriate learning objectives, and guided and facilitated learning.

Argumentation

The results of the ANCOVA test used to determine whether a statistically significant difference existed between the pre- and post-test of M-PBL, H-PBL, and L-PBL are shown in **Table 2**. As shown in **Table 2**, a significant difference existed between the post-test results of the three methods. Thus, it was found that the

Table 2. Argumentation of M-PBL, H-PBL, and L-PBL student

Component of argumentation	Group	Pre-test (mean)	Post-test (mean)	*p*-value (ANCOVA)	Notation* (LSD)
1. Claim	M-PBL	2.15	2.84	0.004	a
	H-PBL	2.06	2.83		a
	L-PBL	1.83	2.41		b
2. Qualifier	M-PBL	2.02	2.42	0.000	a
	H-PBL	1.94	2.00		b
	L-PBL	2.20	2.05		b
3. Evidence	M-PBL	1.62	2.67	0.000	a
	H-PBL	2.20	2.31		b
	L-PBL	1.65	1.90		c
4. Identifying Types of Evidence	M-PBL	1.29	2.47	0.174	Not significance
	H-PBL	1.68	2.51		
	L-PBL	1.54	2.19		
5. Evaluation of the Quality of Evidence	M-PBL	1.67	2.33	0.000	a
	H-PBL	1.94	2.31		a
	L-PBL	1.95	1.40		b
6. Chain and Identification of Reasoning (Warrant)	M-PBL	1.35	2.33	0.000	a
	H-PBL	1.57	1.85		b
	L-PBL	1.17	1.09		c

*Note: The same notation indicates that no significant difference exists between the groups, and a different notation indicates that a significant difference exists with other groups.

Table 2 (continued). Argumentation of M-PBL, H-PBL, and L-PBL student

Component of argumentation	Group	Pre-test (mean)	Post-test (mean)	*p*-value (ANCOVA)	Notation* (LSD)
7. Evaluation of the Quality of Reasoning	M-PBL	1.93	2.57	0.000	a
	H-PBL	2.03	2.26		b
	L-PBL	1.98	1.83		c
8. Concerns of the Student	M-PBL	2.08	2.53	0.001	a
	H-PBL	2.40	2.34		a
	L-PBL	1.97	2.12		b
9. Conclusion and Explanation About the Claim	M-PBL	2.11	2.62	0.002	a
	H-PBL	2.54	2.66		a
	L-PBL	2.41	2.29		b
Sum of Components	M-PBL	16.24	22.91	0.000	a
	H-PBL	18.37	21.08		b
	L-PBL	16.71	17.32		c

*Note: The same notation indicates that no significant difference exists between the groups, and a different notation indicates that a significant difference exists with other groups.

Table 3. Pre-test and post-test of critical thinking skill performance

Component of critical thinking	Group	Pre-test (Mean)	Post-test (Mean)	*p*-value (ANCOVA)	Notation* (LSD)
1. Deduction/Hypothesis	MPBL	0.58	1.00	0.001	a
	HPBL	0.43	0.94		a
	LPBL	0.39	0.78		b
2. Recognition of Assumption	MPBL	0.78	1.71	0.000	a
	HPBL	0.74	1.20		b
	LPBL	0.76	0.98		c
3. Interpretation and Reasoning	MPBL	1.22	2.73	0.000	a
	HPBL	1.23	2.14		b
	LPBL	1.17	1.88		c
4. Inference	MPBL	0.67	0.93	0.001	a
	HPBL	0.63	0.83		a
	LPBL	0.66	0.61		b
5. Decision (evaluation of arguments)	MPBL	0.91	0.98	0.031	a
	HPBL	0.86	1.00		a
	LPBL	0.90	0.88		b
Sum of Component	MPBL	4.16	7.36	0.000	a
	HPBL	3.89	6.11		b
	LPBL	3.88	5.12		c

*Note: The same notation indicates that no significant difference exists between the groups, and a different notation indicates that a significant difference exists with other groups.

M-PBL approach applied to teaching the topic of biology enhanced the argumentation of students. The M-PBL students had better argumentation than H-PBL and L-PBL on the components of a qualifier, evidence, chain and identification of reasoning, and evaluation of reasoning, but not on the identifying types of evidence dimensions, which is not significant.

Critical Thinking

The descriptive statistics of the pre- and post-test CT performance are listed in **Table 3**. Overall, the three teaching methods were generally valuable for enhancing students' CT competence. However, the M-PBL participants performed better in the post-test CT than the L-PBL (control group). Compared to H-PBL, we found an improvement in students' CT components, recognition of assumptions, and reasoning.

DISCUSSION

This study primarily aims to determine the effects of M-PBL on students' argumentation and CT. The results show that students engaging in M-PBL biology learning showed higher levels of argumentation and better CT.

Metacognition and Argumentation

After the intervention, M-PBL students' argumentation scores were significantly higher than those of H-PBL and L-PBL, indicating that they had improved their ability to construct arguments, particularly warrants, reasoning, and more complex fully fledged arguments. Numerous researchers have examined the relationship between metacognition and learning performance (Zhao et al., 2019). This study reveals that metacognitive infusion can help secondary school students effectively engage in argument creation. M-PBL is a way for students to collaborate to solve problems and evaluate processes and solutions. The first step is to identify the problem, after which students gather the necessary information, consider potential solutions, evaluate them, and present their findings. Students must frequently understand how their minds work to solve problems effectively. For example, they must perform critical cognitive tasks, such as remembering, learning, arguing, thinking critically, solving problems, applying, and making rational decisions. (Downing, 2012). In the problem-solving process, metacognition helps students reflect on and analyze their own thoughts (Student's response: *"I also predicted how consumers would react to a restriction on the promotion of sweetened drinks"*), draw conclusions from the analysis, and put what was learned into practice (*"The stakeholder should educate people and younger people to reduce high sugary soft drink consumption"*), see **Table 1**.

Students engaged in the M-PBL units collaboratively solved ill-structured problems, developed arguments, and engaged in CT to support their solutions. This study shows that metacognitive prompts can help secondary school students participate in the argumentation process more effectively. The results support previous research showing that metacognitive prompts significantly affected the learning process and performance (Engelmann et al., 2021), and metacognitive prompting increased problem-solving performance (Hoffman & Spatariu, 2008). In a PBL environment, metacognition, which is implemented as a series of consciously controlled strategies that are well defined and carefully planned, can help students better define problems, search for more relevant information, and construct a more coherent argument.

Many SSIs comprise a broad mix of socio-political-economic-scientific dimensions that include science, technology, society, and the environment. Cultivating arguments in science problem-solving related SSIs, including claims, warrants, evidence, counterclaims, and rebuttals, are fundamental expectations of today's scientifically literate citizens (Yore & Treagust, 2006) (See **Table 1**). The M-PBL students demonstrated scientific literacy, especially CT proficiency and argumentation, when facing SSIs. Statistically significant differences existed in CT and argumentation among the three groups. Participants in the H-PBL and L-PBL groups attempted to use or formulate evidence to bolster or refute their arguments, but both had limited ability to integrate argument elements, in contrast to M-PBL students, who made reasonably sound, evidence-based arguments while critically analyzing socioscientific problems.

Metacognition, Argumentation, and Critical Thinking

Considering that the process of constructing an argument is at the heart of critical thinking, generating or evaluating arguments about issues can contribute to developing and evaluating students' CT skills (Lin, 2014). Students who are capable of producing well defined scientific argumentation demonstrate their ability to perform CT (Giri & Paily, 2020). The contribution of metacognition to the development of CT has been reported; learners who are engaged in more metacognitive activities, especially high-level planning and high-level evaluating strategies, have good CT skills (Ku & Ho, 2014).

M-PBL enables students to substantiate their arguments with evidence or to refute an argument with evidence-based counterclaims or contrary examples, as appropriate. Thus, students will likely develop into skilled thinkers capable of applying their argumentation and CT skills to problem-solving situations. Critical thinking is a subset of reflective thought concerned with determining what we should believe or do (Ennis, 2018). Skilled thinkers demonstrated distinct strengths in their ability to plan specific steps that guide their thinking (high-level planning) and revise their approach in response to evaluation (high-level evaluation); these abilities would result in improved thinking performance. Metacognitive strategies at the highest level would aid in resolving confusion and improving argumentation performance. Contrastingly, HPBL and L-PBL exhibit low-level strategies, demonstrating an awareness of simple questioning or paraphrasing of information without any subsequent execution of the necessary strategies, indicating confusion rather than a solution.

Critical thinking is a necessary component of evaluative reasoning involves assessing the quality of an argument in support of a belief or assertion (Fisher, 2001). Students who are conversant with argumentative knowledge produce more persuasive and critical arguments (Students response *"Assume that the volume of beverages sold, indicative of substantial increases in sales at the population level. I agree that the government prohibits the promotion of high sugar products based on location and price through law"*), see **Table 1**. Argumentative knowledge includes an understanding of what an argument and its components are as well as how to construct a compelling argument. To determine problem-solving, learners need reasoning and arguments implicitly. Processes, such as induction, deduction, inference, value judgment, and conclusion, are used by critical thinkers in problem-solving. Each of these thinking processes require various argumentation abilities. Given the growing awareness of the importance of developing students' CT skills, the difficulty of sustaining problem-based learning, and the paucity of research examining the metacognitive aspects of PBL in the classroom, the current findings have added significance.

CONCLUSION, LIMITATION, AND FUTURE RESEARCH

Developing effective biology teaching is a critical challenge for teachers. This research presents an evaluation of the PBL implementation with metacognitive prompt activities to determine an improvement in students' performance achievement in terms of argumentation and CT. This study contributes to applying metacognitive prompts to PBL in biology learning to improve argumentation skills. Using the M-PBL scenario enables students to gain CT skills. These findings assist teachers in rethinking how students benefit from engaging in M-PBL activities; it should be considered when designing instructions in the socioscientific problem-solving classroom.

Future research is warranted after a successful M-PBL implementation. Future study should investigate how the implementation of M-PBL affects the growth of argumentation and CT in students at various performance levels. The validity of this research should be further enhanced by using more treatment groups. In addition, the content of the developed and applied scenarios of M-PBL should be further extended by adding other topics in biology.

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REFERENCES

Ab Kadir, M. A. (2018). An inquiry into critical thinking in the Australian curriculum: Examining its conceptual understandings and their implications on developing critical thinking as a "general capability" on teachers' practice and knowledge. *Asia Pacific Journal of Education*, *38*(4), 533-549. https://doi.org/10.1080/02188791.2018.1535424

Ariel, B., Bland, M. P., & Sutherland, A. (2022). *Experimental designs* (1st edition). SAGE Publications Ltd.

Ariza, M. R., Quesada Armenteros, A., & Estepa Castro, A. (2021). Promoting critical thinking through mathematics and science teacher education: The case of argumentation and graphs interpretation about climate change. *European Journal of Teacher Education*, *0*(0), 1-19. https://doi.org/10.1080/02619768.2021.1961736

Bencze, L., Pouliot, C., Pedretti, E., Simonneaux, L., Simonneaux, J., & Zeidler, D. (2020). SAQ, SSI and STSE education: Defending and extending "science-in-context." *Cultural Studies of Science Education*, *15*(3), 825-851. https://doi.org/10.1007/s11422-019-09962-7

Botting, D. (2017). Toulmin's logical types. *Argumentation*, *31*(2), 433-449. https://doi.org/10.1007/s10503-016-9414-6

Chris, B., Sackville, A., & Chew Swee, C. (2004). Identifying good practice in the use of PBL to teach computing. *Innovation in Teaching and Learning in Information and Computer Sciences*, *3*(1), 1-19. https://doi.org/10.11120/ital.2004.03010003

Dabbagh, N. (2019). Effects of PBL on critical thinking skills. In M. Moallem, W. Hung, & N. Dabbagh (Eds.), *The Wiley handbook of problem-based learning* (1st ed., pp. 135-156). Wiley. https://doi.org/10.1002/9781119173243.ch6

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97-140. https://doi.org/10.1080/10888691.2018.1537791

Downing, K. (2012). The impact of moving away from home on undergraduate metacognitive development. In H. Kloos (Ed.), *Current topics in children's learning and cognition*. InTech. https://doi.org/10.5772/47944

Drisko, J. W., & Grady, M. D. (2019). Step 3 of EBP: Part 1—Evaluating research designs. *Evidence-Based Practice in Clinical Social Work*, 107-122. https://doi.org/10.1007/978-3-030-15224-6_6

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39-72. https://doi.org/10.1080/03057260208560187

Engelmann, K., Bannert, M., & Melzner, N. (2021). Do self-created metacognitive prompts promote short- and long-term effects in computer-based learning environments? *Research and Practice in Technology Enhanced Learning*, *16*(1), 3. https://doi.org/10.1186/s41039-021-00148-w

Ennis, R. H. (2018). Critical thinking across the curriculum: A vision. *Topoi*, *37*(1), 165-184. https://doi.org/10.1007/s11245-016-9401-4

Erduran, S. (2018). Toulmin's argument pattern as a "horizon of possibilities" in the study of argumentation in science education. *Cultural Studies of Science Education*, *13*(4), 1091-1099. https://doi.org/10.1007/s11422-017-9847-8

Fisher, A. (2001). *Critical thinking: An introduction*. Cambridge University Press.

García-Carmona, A., & Acevedo-Díaz, J. A. (2018). The nature of scientific practice and science education: Rationale of a set of essential pedagogical principles. *Science & Education*, *27*(5-6), 435-455. https://doi.org/10.1007/s11191-018-9984-9

Ghani, A. S. A., Rahim, A. F. A., Yusoff, M. S. B., & Hadie, S. N. H. (2021). Effective learning behavior in problem-based learning: A scoping review. *Medical Science Educator*, *31*(3), 1199-1211. https://doi.org/10.1007/s40670-021-01292-0

Giri, V., & Paily, M. U. (2020). Effect of scientific argumentation on the development of critical thinking. *Science & Education*, *29*, 673-690. https://doi.org/10.1007/s11191-020-00120-y

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. *Journal of Marketing Theory and Practice*, *19*(2), 139-152. https://doi.org/10.2753/MTP1069-6679190202

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2013). Partial least squares structural equation modeling: Rigorous applications, better results and higher acceptance. *Long Range Planning*, *46*(1-2), 1-12. https://doi.org/10.1016/j.lrp.2013.01.001

Hancock, T. S., Friedrichsen, P. J., Kinslow, A. T., & Sadler, T. D. (2019). Selecting socio-scientific issues for teaching: A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science & Education*, *28*(6-7), 639-667. https://doi.org/10.1007/s11191-019-00065-x

Hernández-Ramos, J., Pernaa, J., Cáceres-Jensen, L., & Rodríguez-Becerra, J. (2021). The effects of using socio-scientific issues and technology in problem-based learning: A systematic review. *Education Sciences*, *11*(10), 640. https://doi.org/10.3390/educsci11100640

Hoffman, B., & Spatariu, A. (2008). The influence of self-efficacy and metacognitive prompting on math problem-solving efficiency. *Contemporary Educational Psychology*, *33*(4), 875-893. https://doi.org/10.1016/j.cedpsych.2007.07.002

Hursen, C. (2021). The effect of problem-based learning method supported by Web 2.0 tools on academic achievement and critical thinking skills in teacher education. *Technology, Knowledge and Learning*, *26*(3), 515-533. https://doi.org/10.1007/s10758-020-09458-2

Iordanou, K. (2013). Developing face-to-face argumentation skills: Does arguing on the computer help? *Journal of Cognition and Development*, *14*(2), 292-320. https://doi.org/10.1080/15248372.2012.668732

Jafari, M., & Meisert, A. (2021). Activating students' argumentative resources on socioscientific issues by indirectly instructed reasoning and negotiation processes. *Research in Science Education*, *51*(S2), 913-934. https://doi.org/10.1007/s11165-019-09869-x

Jho, H., Yoon, H.-G., & Kim, M. (2014). The relationship of science knowledge, attitude and decision making on socio-scientific issues: The case study of students' debates on a nuclear power plant in Korea. *Science & Education*, *23*(5), 1131-1151. https://doi.org/10.1007/s11191-013-9652-z

Jiménez-Aleixandre, M. P., & Puig, B. (2012). Argumentation, evidence evaluation and critical thinking. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 1001-1015). Springer Netherlands. https://doi.org/10.1007/978-1-4020-9041-7_66

Kabataş Memiş, E., & Çakan Akkaş, B. N. (2020). Developing critical thinking skills in the thinking-discussion-writing cycle: The argumentation-based inquiry approach. *Asia Pacific Education Review*, *21*(3), 441-453. https://doi.org/10.1007/s12564-020-09635-z

Kim, M., Anthony, R., & Blades, D. (2014). Decision making through dialogue: A case study of analyzing preservice teachers' argumentation on socioscientific issues. *Research in Science Education*, *44*(6), 903-926. https://doi.org/10.1007/s11165-014-9407-0

Ku, K., & Ho, I. (2014). Metacognitive strategies that enhance critical thinking. *Metacognition and Learning*, *5*, 251-267. https://doi.org/10.1007/s11409-010-9060-6

Kuhn, D. (2018). A role for reasoning in a dialogic approach to critical thinking. *Topoi*, *37*(1), 121-128. https://doi.org/10.1007/s11245-016-9373-4

Kuhn, D., Arvidsson, T. S., Lesperance, R., & Corprew, R. (2017). Can engaging in science practices promote deep understanding of them? *Science Education*, *101*(2), 232-250. https://doi.org/10.1002/sce.21263

Lin, S.-S. (2014). Science and non-science undergraduate students' critical thinking and argumentation performance in reading a science news report. *International Journal of Science and Mathematics Education*, *12*(5), 1023-1046. https://doi.org/10.1007/s10763-013-9451-7

Lobato, E. J. C., & Zimmerman, C. (2019). Examining how people reason about controversial scientific topics. *Thinking & Reasoning*, *25*(2), 231-255. https://doi.org/10.1080/13546783.2018.1521870

Magno, C. (2010). The role of metacognitive skills in developing critical thinking. *Metacognition and Learning*, *5*(2), 137-156. https://doi.org/10.1007/s11409-010-9054-4

Matheson, G. J. (2019). We need to talk about reliability: Making better use of test-retest studies for study design and interpretation. *PeerJ*, *7*, e6918. https://doi.org/10.7717/peerj.6918

Mohseni, F., Seifoori, Z., & Ahangari, S. (2020). The impact of metacognitive strategy training and critical thinking awareness-raising on reading comprehension. *Cogent Education*, *7*(1), 1720946. https://doi.org/10.1080/2331186X.2020.1720946

Morris, L. V. (2017). Moving beyond critical thinking to critical dialogue. *Innovative Higher Education*, *42*(5-6), 377-378. https://doi.org/10.1007/s10755-017-9413-z

Naganuma, S. (2017). An assessment of civic scientific literacy in Japan: Development of a more authentic assessment task and scoring rubric. *International Journal of Science Education, Part B*, *7*(4), 301-322. https://doi.org/10.1080/21548455.2017.1323131

Nielsen, J. A. (2013). Dialectical features of students' argumentation: A critical review of argumentation Studies in Science Education. *Research in Science Education*, *43*(1), 371-393. https://doi.org/10.1007/s11165-011-9266-x

Nussbaum, E. M., & Sinatra, G. M. (2003). Argument and conceptual engagement. *Contemporary Educational Psychology*, *28*(3), 384-395. https://doi.org/10.1016/S0361-476X(02)00038-3

Peters, R. (1996). *Jihad in classical and modern Islam: A reader*. Markus Wiener Pub.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371-391. https://doi.org/10.1007/s11165-006-9030-9

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific Argumentation: The effects of content knowledge and morality. *International Journal of Science Education*, *28*(12), 1463-1488. https://doi.org/10.1080/09500690600708717

Seel, N. M. (2012). Experimental and quasi-experimental designs for research on learning. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 1223-1229). Springer US. https://doi.org/10.1007/978-1-4419-1428-6_716

Songsil, W., Pongsophon, P., Boonsoong, B., & Clarke, A. (2019). Developing scientific argumentation strategies using revised argument-driven inquiry (rADI) in science classrooms in Thailand. *Asia-Pacific Science Education*, *5*(1), 1-22. https://doi.org/10.1186/s41029-019-0035-x

Streiner, D. L., Norman, G. R., & Cairney, J. (2014). Health Measurement Scales: A practical guide to their development and use. In *Health Measurement Scales* (3rd ed.). Oxford University Press. https://oxfordmedicine.com/view/10.1093/med/9780199685219.001.0001/med-9780199685219

Syaiful, Huda, N., Mukminin, A., & Kamid. (2022). Using a metacognitive learning approach to enhance students' critical thinking skills through mathematics education. *SN Social Sciences*, *2*(4), 31. https://doi.org/10.1007/s43545-022-00325-8

Taber, K. S. (2015). Affect and meeting the needs of the gifted chemistry learner: Providing intellectual challenge to engage students in enjoyable learning. In M. Kahveci & M. Orgill (Eds.), *Affective Dimensions in Chemistry Education* (pp. 133-158). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-45085-7_7

Tanner, K. D. (2013). Structure matters: Twenty-one teaching strategies to promote student engagement and cultivate classroom equity. *CBE – Life Sciences Education*, *12*(3), 322-331. https://doi.org/10.1187/cbe.13-06-0115

Thonney, T., & Montgomery, J. C. (2019). Defining critical thinking across disciplines: An analysis of community college faculty perspectives. *College Teaching*, *67*(3), 169-176. https://doi.org/10.1080/87567555.2019.1579700

Valladares, L. (2021). Scientific literacy and social transformation: Critical perspectives about science participation and emancipation. *Science & Education*, *30*(3), 557-587. https://doi.org/10.1007/s11191-021-00205-2

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education*, *14*(4), 659-680. https://doi.org/10.1007/s10763-014-9605-2

von der Mühlen, S., Richter, T., Schmid, S., & Berthold, K. (2019). How to improve argumentation comprehension in university students: Experimental test of a training approach. *Instructional Science*, *47*(2), 215-237. https://doi.org/10.1007/s11251-018-9471-3

Voss, J. F. (2005). Toulmin's model and the solving of ill-structured problems. *Argumentation*, *19*(3), 321-329. https://doi.org/10.1007/s10503-005-4419-6

Wechsler, S. M., Saiz, C., Rivas, S. F., Vendramini, C. M. M., Almeida, L. S., Mundim, M. C., & Franco, A. (2018). Creative and critical thinking: Independent or overlapping components? *Thinking Skills and Creativity*, *27*, 114-122. https://doi.org/10.1016/j.tsc.2017.12.003

Weng, W.-Y., Lin, Y.-R., & She, H.-C. (2017). Scaffolding for argumentation in hypothetical and theoretical biology concepts. *International Journal of Science Education*, *39*(7), 877-897. https://doi.org/10.1080/09500693.2017.1310409

Westen, D., & Rosenthal, R. (2003). Quantifying construct validity: Two simple measures. *Journal of Personality and Social Psychology*, *84*(3), 608-618. https://doi.org/10.1037/0022-3514.84.3.608

Wynn, C. T., & Okie, W. (2017). Problem-based learning and the training of secondary social studies teachers: A case study of candidate perceptions during their field experience. *International Journal for the Scholarship of Teaching and Learning*, *11*(2), 16. https://eric.ed.gov/?id=EJ1150530

Wynn, C. T., Ray, H., & Liu, L. (2019). The Relationship between Metacognitive Reflection, PBL, and Postformal Thinking among First-Year Learning Community Students. *Learning Communities: Research & Practice*, *7*(2), 3. https://eric.ed.gov/?id=EJ1240095

Xiao, S., & Sandoval, W. A. (2017). Associations between attitudes towards science and children's evaluation of information about socioscientific issues. *Science & Education*, *26*(3-4), 247-269. https://doi.org/10.1007/s11191-017-9888-0

Yacoubian, H. A., & Khishfe, R. (2018). Argumentation, critical thinking, nature of science and socioscientific issues: A dialogue between two researchers. *International Journal of Science Education*, *40*(7), 796-807. https://doi.org/10.1080/09500693.2018.1449986

Yang, X., Zhao, G., Yan, X., Chao, Q., Zhao, X., Lu, T., & Dong, Y. (2021). Pre-setting stances for students during collaborative argumentation: Parallel thinking versus adversarial thinking. *Research in Science Education*. https://doi.org/10.1007/s11165-021-10035-5

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy—empowering research and informing instruction. *International Journal of Science Education*, *28*(2-3), 291-314. https://doi.org/10.1080/09500690500336973

Young, S. A., Newton, A. R., Fowler, S. R., & Park, J. (2021). Critical thinking activities in Florida undergraduate biology classes improves comprehension of climate change. *Journal of Biological Education*, 1-12. https://doi.org/10.1080/00219266.2021.1877785

Zeidler, D. (2015). Socioscientific issues. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 998-1003). Springer Netherlands. https://doi.org/10.1007/978-94-007-2150-0_314

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education: Vol. II* (pp. 697-726). Routledge, Taylor & Francis Group.

Zenker, F. (2018). Introduction: Reasoning, argumentation, and critical thinking instruction. *Topoi*, *37*(1), 91-92. https://doi.org/10.1007/s11245-016-9416-x

Zhao, N., Teng, X., Li, W., Li, Y., Wang, S., Wen, H., & Yi, M. (2019). A path model for metacognition and its relation to problem-solving strategies and achievement for different tasks. *ZDM*, *51*(4), 641-653. https://doi.org/10.1007/s11858-019-01067-3

APPENDIX 1

M-PBL Teaching and Learning Steps in the Digestive Module

The steps of teaching and learning		PBL in Digestive Modul	Metacognitive prompt
Presentation of ill-structured real-world problems	Students were engaged in the process of problem identification, generating ideas to inquire about and formulate hypotheses.	Students brainstorm about nutrition: the benefits of food for health, cases of obesity, and malnutrition. Problem identification: • Identification of the root problems of obesity and malnutrition – a dearth of nutritious food. • The question: how do we create sustainable systems for healthy diets? Students in groups collect information: • healthy food, • human digestion system and absorption of food, • Vitamin and minerals, • malnutrition, and obesity crisis. Students dialogue with peers to formulate opinions/hypotheses.	The teacher facilitates students: • Using a mind map to relate nutritious food and obesity and malnutrition • Reflection: check and recheck problem identification
Designing a solution to the problem.	Through problem design, students were aware that they needed more information and skills to "dig out" solutions independently.	Students in a group create the design of problems-solutions (how to create sustainable systems for healthy diets?) Designing solution: • How to make a good lunch menu? • Promoting to young people a healthy lifestyle by consuming halal and nutritious food.	The teacher facilitates students: • Using a flowchart to identify the problem-solution process • Reflection: check whether the design problems-solutions are rational and achievable or not.
Group-structured inquiries	Students in the group developed self-directed learning skills to answer problems through structured group inquiry.	Groupwork creates an exploration: • A good lunch menu: o Conception on a health food menu o Nutrition: carbohydrate, fat, protein, minerals, vitamins o The digestion, absorption, and transportation of nutrients o Creative variety lunch menu to avoid obesity and malnutrition. • Promoting to young people a healthy lifestyle by consuming halal and nutritious food. o The conception of a healthy lifestyle o Step to a healthy lifestyle o Sport and food consumption for a healthy lifestyle o Promotion of a healthy lifestyle to young people.	Teachers and students use an exploratory investigation checklist to evaluate: • The theoretical basis of identification problem-solution • Investigation plan: hypothesis, investigation design • The result, data collection, and analysis. • Summary and recommendation. Students and teachers are conducting ongoing monitoring and review.
Develop and present artifacts and exhibit	The creation of artifacts and exhibits of group-structured inquiries.	Groupwork creates innovative products design (posters, papers, videos) about a good lunch menu and a call for action to promote healthy food. Presentation and classroom discussion.	Teachers facilitate students: • Groupwork presentation and classroom discussion • Mutual interaction to evaluate group work product and presentation.
Evaluation and reflection.	Students developed self-assessment and self-reflection habits by continually asking themselves the question.		

APPENDIX 2

Rubric to Assess Students' Argument

Dimension	Score			
	0	1	2	3
Claim	The student makes no answer.	The students' response not structured as a claim.	The student identifies only a portion of the claim being made.	The student correctly recognized the asserted claim.
Qualifier	The student makes no answer.	The student's answer fails to declare that there are no qualifiers included in the claim.	The student recognizes a qualifier to a certain extent(s)	The student correctly identifies the majority of the claim's qualifiers.
Evidence	The student makes no answer.	The student fails to identifies instances in which the evidence contradicts the claim.	The student response identifies instances in which the evidence contradicts the claim.	The student correctly identifies the overwhelming majority of evidence that supports the claim.
Types of evidence identification	The student makes no answer.	The students' answer is inaccurate in identifying types of evidence.	The student correctly classifies certain types of evidence.	All evidence is appropriately classified as fact, theory, or opinion by the learner.
Quality evidence evaluation	The student makes no answer.	The students' answer does not accurately evaluate or discuss the evidence's quality.	The student assesses and discusses some of the evidence's quality and decides the evidence's quality was relevant or irrelevant.	The student assesses and discusses the validity and reliability of evidence.
Chain of reasoning (warrant)	The student makes no answer.	The student's answer is inadequate in explaining the connection between evidence and the claim.	The student explains some of the reasoning concerning the evidence.	The student explains the logical reasoning related to the evidence.
Reasoning type identification	The student makes no answer.	The students' answer is inaccurate in identifying the various types of reasoning.	The student correctly recognizes several different types of reasoning.	The student assesses the reasoning's quality and explains his/her assessment.
Reasoning quality evaluation	The student makes no answer.	The students' answer does not accurately assess the reasoning's quality.	The student assesses certain aspects of the reasoning's quality.	The student assesses the reasoning's quality and explains his/her assessment.
The student concern	The student makes no answer.	The student response does not raise any new pertinent concerns.	The student brings up several new pertinent issues.	The student explicitly promotes new pertinent interests and explains them in the form of counterarguments, rebuttals, or new questions.
Conclusion and explanation about the claim	The student makes no answer.	The students' answer does not conclude whether to receive, refuse or withstand judgment on the claim.	The student concludes whether to receive, refuse or withstand judgment on the claim.	The student concludes whether to receive, refuse or withstand judgment on the claim and explains the reasoning.

APPENDIX 3

Samples Question of Critical Thinking Dimensions

Dimensions	Definition	Sample question
1. Recognition of Assumption	Recognition of assumption is the capacity of the student to identify unstated assumptions or presuppositions implicit in given statements or assertions.	A recent review of the global status of vitamin C found a high prevalence of deficiency, especially in low- and middle-income countries. Numerous countries have implemented a program to increase vitamin C intake through dietary promotion and supplementation. What is the logical premise upon which these programs operate?
2. Deduction	The capacity of students for deductive reasoning from given statements or premises; recognition of the relationship of implication between propositions; and making an inference based on widely-accepted facts or premises.	Cigarette smoking during childhood causes significant health problems among young people. What is a rational deduction and hypothesis referring relationship between smoking and health problems?
3. Interpretation and reasoning	Interpretation and reasoning is the capacity to examine and evaluate things logically, using logical consideration to make decisions or solve problems based on new or existing knowledge.	Coronary heart disease happens when the heart's arteries cannot give enough oxygen-rich blood to the heart. It is the world's leading cause of death. The accumulation of plaque in the heart's coronary arteries, which can partially or obstruct blood flow, is a common cause of coronary heart disease. How beneficial is healthy behavior to prevent us from heart disease?
4. Inference	The inference is formulating a conclusion that is drawn from evidence and reasoning.	The primary protein found in our red blood cells is hemoglobin. It transports and distributes oxygen throughout our bodies. When we are anemic, our hemoglobin level is also low. What is the relationship between anemia and the energy required for movement?
5. Decision-making	The cognitive process's ability leads to choosing a reasonable belief or plan of action from multiple feasible alternatives.	Since the 2000s, Indonesians have increased their meals consumption, particularly from fast-food restaurants. Around 60% of Indonesian teenagers visited fast-food restaurants at least once a month, and 25% regularly visited (two times per week). Obesity prevalence increased consistently as fast-food restaurants were frequented. Even though 70% of persons who visit fast-food restaurants would hypothetically prefer healthier fast-food products if they were available, just 15% claimed they ever order based on nutritional information. What is the rationale for educating teens about fast-food consumption, mainly to prevent obesity?