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# The Effectiveness of Science E-modules Containing SSI with the PBL Model to Improve Critical Thinking Skills and Science Literacy of Junior High School Students

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**Abstract:** The limited availability of teaching materials that support the development of critical thinking skills and scientific literacy in a contextual and reflective manner. Textbooks used in schools generally focus on memorizing concepts and do not encourage the exploration of complex socio-scientific issues. This, study aims to test the effectiveness of a science e-module containing Socio-Scientific Issues (SSI) with a Problem-Based Learning (PBL) model in improving critical thinking skills and scientific literacy of junior high school students. The study used a one-group pretest-posttest design as part of the assessment stage in the R&D Plomp model. The research subjects consisted of 44 eighth-grade students of SMP Negeri 2 Singaraja, who were selected purposively. Data were collected through a critical thinking skills test based on Ennis indicators and a science literacy test based on Vision III. The analysis results showed a significant increase in the posttest scores of critical thinking skills (N-Gain = 0.70) and science literacy (N-Gain = 0.58), with a high effect size value. Analysis per indicator showed the highest increase in the Situation and Reason indicators (critical thinking), as well as Critical Thinking and Acting (science literacy). The e-module also encouraged active student involvement in problem-based learning and contextual issues.

**Keywords**: Critical thinking skills; E-module; Problem-based learning; Scientific literacy; Socio-scientific issues

## Introduction

The 21st century is marked by major changes in various aspects of life influenced by advances in digital technology, artificial intelligence, globalization, and the complexity of environmental issues such as climate change and ecosystem degradation. These changes require education to produce a generation that not only masters academic content but also possesses higher-order thinking skills, scientific literacy, and social sensitivity. Science education plays a crucial role in equipping students with critical thinking skills and scientific literacy, two essential components for facing real-life challenges scientifically and responsibly (Hussein, 2021). In the context of Indonesian education, the Independent Curriculum (Curriculum Merdeka) is a concrete manifestation of the 21st-century educational transformation, emphasizing competency-based learning, character building, and contextual learning. One of the main priorities of this curriculum is strengthening the Pancasila Student Profile, particularly critical reasoning and global diversity, which are directly linked to critical thinking skills and scientific literacy (Anggraeni et al., 2023).

Critical thinking is an aspect of higher-order thinking skills that plays a crucial role in learning, particularly in science education. Experts define it from complementary perspectives. Putri et al. (2021), define

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critical thinking as the process of consciously gathering, analyzing, and conceptualizing information to produce more creative decisions. Meanwhile, (Ennis & Philosophy Documentation Center, 1991), emphasizes the reflective and rational dimensions of critical thinking, which focus on assessing what to believe or do. Other approaches highlight affective and social elements, such as Watson and Glaser, who view critical thinking as a combination of interrelated attitudes, knowledge, and skills. In practice, critical thinking involves not only the ability to analyze and evaluate but also requires creative thinking (Shamboul, 2022), as solutions to problems cannot always be achieved through formal logic alone, but also through imagination and the discovery of new ideas. Therefore, critical thinking is a central competency in 21st-century learning, requiring students to be able to approach complex problems scientifically, logically, and ethically.

In addition to the critical thinking skills described above, scientific literacy is also an essential component of 21st-century science education, particularly in the context of meaningful and contextual learning. Scientific literacy has been a key concept in science education since the late 1950s. This concept emphasizes not only understanding scientific content but also the individual's ability to use scientific knowledge in decision-making, both personally and socially. According to DeBoer (2000), scientific literacy encompasses the ability to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions. Optimal scientific literacy skills will enable students to achieve impactful learning outcomes. Learning outcomes are all forms of output produced by the learning process, including knowledge, skills, and attitudes (Sanjayanti et al., 2022). As time goes by, scientific literacy demands individuals' critical engagement with issues at the intersection of science, technology, and society.

Valladares (2021), defines scientific literacy as the ability of students to participate in scientific discussions as reflective citizens. This includes the competency to explain phenomena scientifically, evaluate and design investigations, and interpret data and evidence scientifically. The National Research Council (in the Ministry of Education and Culture, 2017 in (Fortus et al., 2022) adds that scientific literacy reflects science as a social and epistemic practice, which is interdisciplinary and meaningful in real life. To clarify the direction of science education development, (Zidny et al., 2020), proposed three visions of scientific literacy: Vision I, focusing on mastery of basic scientific knowledge and skills; Vision II, emphasizing critical thinking and problem-solving skills, as well as awareness of the social and ethical implications of science; and Vision III, which emphasizes critical practice through ethical reflection, social responsibility, and the application of science to solve real-world problems. These three visions are not contradictory but complementary, forming a spectrum of scientific literacy development. However, in the context of global challenges and the needs of the 21st century, Vision III is considered the most relevant as a transformative framework for science education. This study specifically chose Vision III scientific literacy because it aligns with the Socio-Scientific Issues (SSI)-based learning approach used.

Sjöström et al. (2018), simplify the differences between the three visions: Vision I focuses on scientific content, Vision II on applications in everyday life, and Vision III on the relationship between science and society. Vision III views science education as a politically conscious practice. Its goal is to foster critical awareness, social justice, and active engagement in environmental, cultural, and global issues (Washington et al., 2024). This approach encourages students not only to understand science but also to act ethically and responsibly in a social context. In line with Vision III, a Bildung-oriented science education approach is considered relevant because it emphasizes the formation of a reflective and useful scientific character. According to Shofiyah et al. (2020), this approach fosters scientific literacy through three main approaches: strengthening critical and reflective thinking regarding scientific knowledge and its impacts, developing real-world problem-solving skills, and fostering social responsibility and civic awareness in scientific decision-making.

To support the implementation of Vision III, Carter and Smith in Sulaiman et al. (2025) proposed six principles for future-oriented science education: socially critical; encompassing the history and philosophy of science; focusing on sustainability; incorporating a postcolonial perspective; fostering a sense of wonder and transcendence, and oriented toward social change through meaningful mastery of science. This Vision III approach, also known as STSE (Science, Technology, Society, and Environment), emphasizes the close relationship between science and various aspects of life. The core competencies in Vision III science literacy include (Himmah et al., 2024): Broad Scientific Knowledge: understanding fundamental scientific concepts and digital literacy; Pluralistic Perspective: engaging with science from multiple perspectives, including interdisciplinary, critical, historical, philosophical, sociological, and indigenous perspectives; Ethical-Socio-Political Engagement: recognizing and engaging with the ethical, social, and political dimensions of scientific issues; Relational-Existential Understanding: recognizing the interconnectedness of all things and the impact of science on our lives and the world; Critical Thinking and Action: being prepared to take informed action on global and local (glocal) issues. These five competencies form the transformative framework of Vision III science literacy, emphasizing not only mastery of scientific concepts but also ethical decision-making with social impact. Despite the immense potential of Vision III science literacy in learning, Indonesian students' literacy and critical thinking skills remain relatively low. The 2022 PISA results showed that only 34% of Indonesian students achieved the minimum level of science literacy, far below the OECD average of 76%. Similarly, students' critical thinking skills remain low, as reported in national assessments and several studies (Yusmar & Fadilah, 2023). This problem is partly due to the limited teaching materials that support the development of critical thinking skills and science literacy in a contextual and reflective manner. Textbooks used in schools generally focus on memorization of concepts and do not encourage exploration of complex socio-scientific issues (Viehmann et al., 2024). The dominant teacher-centered learning approach and lack of interactivity also pose obstacles to the development of 21st-century skills.

This situation highlights the need for learning interventions relevant to the 21st-century context, one of which is through the use of e-modules based on appropriate approaches. To address this challenge, innovative teaching materials are needed that integrate learning approaches appropriate to 21st-century characteristics. One potential alternative is the development of a science e-module containing Socio-Scientific Issues (SSI) with the integration of Problem-Based Learning (PBL). Socio-Scientific Issues (SSI) are social dilemmas related to concepts or technology in science. The resolution of these problems is characterized by informal reasoning, which involves the formation and evaluation of positions within complex situations (Sadler, 2004). SSI incorporate contextual and current issues in society, making them relevant to students' lives and enhancing learning motivation (Karakaş, 2022; Sadler & Zeidler, 2004).

Therefore, integrating e-modules with the SSI-based PBL model has strong potential to simultaneously improve critical thinking skills and scientific literacy. Although the Socio-Scientific Issues (SSI) approach and the Problem-Based Learning (PBL) model have been extensively researched separately, studies on the effectiveness of e-modules that specifically integrate the two in the context of science learning at the junior high school level are still limited. However, the use of e-modules containing contextual issues and problem-based learning is believed to improve critical thinking skills and scientific literacy simultaneously. Therefore, an empirical study is needed to examine the extent to which a science e-module containing SSI with a PBL model is effective in improving students' 21st-century competencies. Based on this background, this study aims to test the effectiveness of a science e-module containing Socio-Scientific Issues (SSI) with a Problem-Based Learning (PBL) model in improving critical thinking skills and scientific literacy of junior high school students.

## Method

This research is a research and development (R&D) study using the Plomp model. This article focuses on the assessment phase to test the effectiveness of a science e-module containing Socio-Scientific Issues (SSI) based on Problem-Based Learning (PBL). The research design used at this stage was a quasi-experimental one-group pretest-posttest design. The effect of e-module use on students' critical thinking skills and scientific literacy was analyzed through a comparison of pretest and posttest scores. The effectiveness test subjects consisted of three stages: 3 students (pre-test), 9 students (small group), and 32 students (large group), for a total of 44 eighth-grade students at SMP Negeri 2 Singaraja, selected purposively. The e-module tested for effectiveness in this study met the validity criteria of subject matter experts (Gregory's validation coefficient of 0.64), language experts (96.9%), and media experts (98.46%). Furthermore, the e-module also passed readability and practicality tests. The readability test, with nine students as respondents, yielded a score of 92.2%. The practicality test, with nine students, yielded a score of 92.2%, and the teacher a score of 98.75%. These test results demonstrate that the e-module meets the requirements for validity, readability, and practicality, according to users (students and teachers).

The instruments used in this study included: a critical thinking skills test based on Ennis' indicators; and a science literacy test based on Vision III science literacy indicators. In this study, to ensure that the critical thinking skills (CBS) and scientific literacy (LS) tests were suitable for use as valid and reliable measurement tools, the instruments were subjected to a phased validity and reliability test. The initial stage involved a content validity test conducted by two lecturers, subject matter experts in science education. Following the content validity test, the instruments were then empirically tested through a pilot test with students. Empirical validity was analyzed based on the difficulty level and discriminatory power of the items. The analysis showed that the 15 items were of good quality and statistically acceptable. Reliability testing was conducted using Cronbach's Alpha technique in SPSS. The calculation results showed that the reliability value for the critical thinking skills instrument was 0.708, and for the scientific literacy instrument was 0.722. Both values are above the threshold of 0.7, indicating that the instruments have high internal consistency and are reliable for use in measurement.

Thus, the critical thinking and scientific literacy test instruments in this study have undergone a systematic validation and testing process and have been declared valid and reliable, making them suitable for measuring students' abilities in the context of Problem-Based Learning-based science learning that addresses Socio-Scientific Issues. The implementation procedure included administering a pretest, implementing the e-module in classroom instruction, and administering a posttest after the learning process. The data obtained were analyzed using gain scores, inferential statistical analysis (paired t-tests or Wilcoxon tests) to test for significant differences, and calculating effect sizes to determine the strength of the e-module's influence on critical thinking and scientific literacy skills.

## Result and Discussion

*Research Results*

The data collected in this study were pretest and posttest data for critical thinking skills and scientific literacy.

*Initial Test*

The first stage of the effectiveness test involved three eighth-grade students selected purposively, representing high, medium, and low ability categories. The purpose of this test was to obtain an initial indication of the e-module's effectiveness in improving critical thinking skills (CBT) and scientific literacy (LS), as well as to identify potential improvements before wider implementation. Data were analyzed descriptively, by calculating the difference between pretest and posttest scores and the normalized gain score (g). The results of the analysis are shown in Table 1.

**Table 1.** Summary of Pretest and Posttest Results for CBT and LS for Phase 1 Testing

| Aspect | Average Score | | Gain Score |
|---|---|---|---|
| | Pretest | Posttest | |
| KBK | 58 | 82 | 0.579 |
| LS | 58 | 82 | 0.579 |

Based on Susanto's (2012) classification, the gain scores for the KBK (0.579) and LS (0.636) are in the moderate category, indicating that the use of e-modules contributed to improving student abilities, particularly in critical thinking skills and scientific literacy. Although further testing is needed in a larger group, this still requires further testing.

*Small Group Test*

The second stage was an extension of the first test, involving nine students selected based on varying academic abilities. The ability distribution consisted of three students in the high, three in the medium, and three in the low categories. The implementation procedure was similar to the first stage: students took a pretest, learned using the e-module on one topic, and then a posttest. Analysis was conducted descriptively by comparing the initial and final scores for each participant and calculating the gain score. The results of the analysis are shown in Table 2.

**Table 2.** Recapitulation of KBK and LS Pretest and Posttest Results for Phase 2 Testing

| Aspect | Average Score | | Gain Score |
|---|---|---|---|
| | Pretest | Posttest | |
| KBK | 49 | 83 | 0.667 |
| LS | 52 | 85 | 0.692 |

Based on Susanto's (2012) classification, the gain score for the KBK (0.667) and LS (0.692) is categorized as moderate, indicating that the use of the e-module contributed to improving students' abilities, particularly in critical thinking and scientific literacy. Although further testing is needed in larger groups, this requires further testing.

*Large Group Test*

A total of 32 eighth-grade students at SMP Negeri 2 Singaraja participated in the learning using the SSI-based e-module using the PBL model on the topic of the Excretory System. The activity began with a pretest, followed by four learning sessions, and concluded with a posttest. After completing the four sessions of learning using the e-module, students were given a posttest to measure their KBK and LS. The summary of the pretest and posttest scores for the large group test is presented in Table 3.

**Table 3.** Summary of Student Pretest and Posttest Scores for the Large Group Test of the E-Module

| Statistics | KBK | | LS | |
|---|---|---|---|---|
| | Pretest | Posttest | Pretest | Posttes |
| Number of Students | 32 | 32 | 32 | 32 |
| Highest Score | 80 | 100 | 80 | 100 |
| Lowest Score | 40 | 73.30 | 53.39 | 73.30 |
| Average | 64.90 | 89.60 | 69.60 | 87.10 |
| Standard Deviation | 9.46 | 6.97 | 5.60 | 5.60 |

*Critical Thinking Skills (CBC) Effectiveness Test Results*

The results of the critical thinking skills (CBC) measurement showed an increase in the average score from 64.9 in the pretest to 89.6 in the posttest. This increase resulted in a gain score of 0.70 (high category). The Wilcoxon test was used because the data were not normally distributed. The results showed a significant difference between the pretest and posttest ($p < 0.05$), indicating that the use of the e-module significantly improved students' critical thinking skills. The CBC effect size of 0.875 (very large category) indicates that the use of the SSI-containing e-module with the PBL model had a strong practical impact on improving students' critical thinking skills.

*Results of the LS Effectiveness Test*

Students' scientific literacy skills increased from an average score of 69.6 to 87.1, with a gain score of 0.58 (moderate category). The Wilcoxon test was also performed on the LS data because it was not normally distributed. The results showed a significant result ($p < 0.05$), confirming that the e-module contributed positively to improving scientific literacy. The LS effect size analysis yielded a value of 0.859 (very large). The analysis showed that the SSI-containing e-module with the PBL model effectively improved students' critical thinking skills and scientific literacy, both statistically and practically.

*Analysis Results per CBC Aspect*

To obtain a more comprehensive picture of the e-module's effectiveness in improving critical thinking skills, an analysis was conducted based on indicators referenced in the Ennis framework. This analysis grouped the test items into their respective indicators and then calculated the average percentage increase from pretest to posttest. The summary results are presented in Table 4.

**Table 4.** Analysis of Percentage Improvement per CBC Indicator

| Indicator | Question No. | % Increase per Question | Average Increase | Category |
|---|---|---|---|---|
| Reason | 1, 6 | 87.50; 42.86 | 65.18 | High |
| Inference | 2, 7, 11, 15 | 40.00; 36.36; 0.00; 47.62 | 31.50 | Medium |
| Situation | 3, 12 | 64.71; 81.25 | 72.98 | High |
| Clarity | 4, 8, 13 | 33.33; 45.00; 22.73 | 33.69 | Medium |
| Focus | 5, 10, 14 | 61.11; 6.90; 42.11 | 36.71 | Medium |
| Overview | 9 | 17.39 | 17.39 | Low |

Based on the analysis of the average increase in student scores for each critical thinking skill indicator, the following results were obtained: Situation showed the highest increase with an average of 72.98% (high category). This reflects the e-module's success in training students to consider the problem context in-depth in their thinking process; Reasoning also showed a high increase (65.18%), indicating the e-module's effectiveness in developing students' ability to construct scientific reasoning and arguments; Focus, Clarity, and Inference were in the moderate category, with average increases of 36.71%, 33.69%, and 31.50%, respectively. Although classified as moderate, these results indicate developments that still require further strengthening in these aspects, particularly in encouraging students to be more focus and clear in their thinking and draw logical conclusions; The Overview indicator achieved the lowest increase, only 17.39% (low category), indicating that the e-module was not optimal in developing students' ability to understand the general picture and construct a comprehensive evaluation of a problem.

*Results of the Analysis per LS Indicator*

Each question item was mapped to a specific indicator, and then the average percentage improvement was calculated from the pretest and posttest results. This analysis provides an overview of the extent to which the e-module fosters students' understanding of science in a broad, reflective, and socially relevant context.

**Table 5.** Summary of Average Improvement per LS Indicator

| Indicator | Question No. | Increase per Question (%) | Average Increase | Category |
|---|---|---|---|---|
| Broad Scientific Knowledge | 1, 5, 11 | 36.84; 11.54; 10.71 | 19.70 | Low |
| Pluralistic Perspective | 2, 6, 12 | 29.41; 28.57; 16.67 | 24.88 | Medium |
| Relational-Existential Understanding | 3, 7, 10, 14 | 23.81; 52.94; 6.90; 25.00 | 27.16 | Medium |
| Critical Thinking and Action | 4, 8, 15 | 55.56; 40.00; 12.00 | 35.85 | Medium |
| Ethical-Socio-Political Engagement | 9, 13 | 27.27; 30.43 | 28.85 | Medium |
| Broad Scientific Knowledge | 1, 5, 11 | 36.84; 11.54; 10.71 | 19.70 | Low |

Analysis of the average score increase for the science literacy indicators shows that: Critical Thinking and Action had the highest average increase of 35.85%, although it still falls into the moderate category. This indicates that PBL-SSI is quite effective in developing students' critical thinking and scientific-based decision-making skills in real-life contexts; The Ethical-Socio-Political Engagement, Relational-Existential Understanding, and Pluralistic Perspective indicators also fell into the moderate category, with average increases ranging from 24.88% to 28.85%. This indicates that the e-module has helped foster student engagement with the social, ethical, and existential dimensions of the scientific issues discussed; Meanwhile, the Broad Scientific Knowledge indicator achieved the lowest average increase, at only 19.70% (low category). This indicates that although the e-module provides a rich context, the reinforcement of basic scientific concepts still needs improvement, for example by adding a concept summary section or conceptual reinforcement exercises. In general, all five indicators of Vision III Scientific Literacy showed positive improvement, with most falling within the moderate category. This indicates that the integration of the Problem-Based Learning model and the Socio-Scientific Issues context was quite successful in improving students' scientific literacy, particularly in the reflective, social, and practical aspects. Although the conceptual aspect still requires strengthening.

*Observation Results During the Implementation of the SSI-Containing E-module with the PBL Model*

Based on observations conducted during four learning sessions, students generally demonstrated active engagement in the learning process. This is demonstrated through four main indicators:

*Asking and responding to peers' opinions*

Most students appeared active in discussions, both in groups and as a class. They were able to express their opinions, respond to their peers' arguments, and ask questions that demonstrated their understanding of the issues discussed. This questioning and responding to opinions became even more lively and lively when students discussed the SSI issues raised in the e-module. This demonstrated students' interest in the social science issues discussed in the lesson.

*Curiosity during investigations*

During the investigation phase of the PBL model, students displayed high enthusiasm. They appeared eager to seek information from various sources, both from teaching materials and from discussions with their group mates. This reflected an internal drive to understand the material more deeply, especially when solving problems raised in the e-module. In addition to the competition for excellence, students' active participation was also driven by the belief that they had to prove whether their arguments regarding the problem (written when developing the initial hypothesis) were correct or incorrect.

*Active participation in groups*

The entire group demonstrated good cooperative dynamics. Every group member participated in the discussion. No single student dominated. This was due to the fact that they had divided roles and tasks within the group. This indicates that the e-module successfully facilitated equitable participation in the collaborative process.

*Ability to prepare reports or their own work*

In the final stage of learning, students were asked to prepare a report on their investigations. Based on observations, most students were able to prepare reports with a logical structure, clear language, and content that reflected their understanding of the material. Although some students still needed further guidance on writing, overall, their reports reflected good learning outcomes. These observational results support the quantitative findings of the effectiveness test, which found that the use of the e-module not only improved students' cognitive achievement but also encouraged active engagement, curiosity, and collaborative skills, essential characteristics of 21st-century learning.

*Discussion*

An initial effectiveness test with three students illustrated the e-module's contribution to improving critical thinking skills and scientific literacy. Pretest and posttest results showed an increase in scores, with an average gain score of 0.579 for the KBK and 0.636 for the LS, both of which fall into the moderate category according to Susanto's (2012) classification. These findings indicate that the e-module has the potential to improve students' abilities, regardless of their initial abilities. Subsequent testing with nine students confirmed the previous results. The KBK score increased from an average of 49 to 83, with a gain score of 0.667, while the LS score increased from 52 to 85, with a gain score of 0.692. Both scores indicate moderate effectiveness and consistent effectiveness of the e-module at the small group level. The main implementation phase was conducted on a classroom scale, involving 32 eighth-grade students. Pretest and posttest results showed an average increase in the KBK score from 64.8 to 89.6, with a gain score of 0.70 (high category), while the LS score increased from 69.6 to 87.1, with a gain score of 0.58 (moderate category). The Wilcoxon Signed Rank Test showed a significant difference between the pretest and posttest for both the KBK and LS ($p = 0.000 < 0.05$).

In addition to being statistically significant, the calculated effect size ($r = 0.875$ for the KBK and $r = 0.859$ for the LS) indicated a very large effect according to Cohen (1988). This indicates that the e-module intervention had a significant and strong impact on improving both competencies. Analysis of the distribution of improvement showed that the majority of students experienced moderate improvement in the KBK (53%) and LS (88%). These results indicate that the e-module was able to have a positive impact evenly across various levels of student ability. This aligns with the characteristics of PBL-based learning, which emphasizes collaboration and open exploration of contextual problems. Analysis by indicator shows that in the KBK, the Reason and Situation indicators experienced the highest improvement, indicating that the e-module successfully fostered students' argumentative skills and understanding of context. Conversely, the Overview and Inference indicators showed low improvement, providing input for improving the design of future explicit thinking activities. In scientific literacy, the highest improvement occurred in the Critical Thinking and Action indicator (35.85%), followed by Ethical-Socio-Political Engagement and Relational-Existential Understanding. However, the lowest improvement was recorded in the Broad Scientific Knowledge indicator (19.70%), indicating the need for additional emphasis on basic science concepts.

Non-participatory observation data during the lesson supported the quantitative data. Students demonstrated high engagement, good group collaboration, and the ability to convey ideas coherently. Active discussions and investigations into contextual problems demonstrated that the e-module successfully facilitated an active and meaningful learning process, in line with the characteristics of 21st-century learning. The effectiveness of this e-module view that the PBL model fosters social, reflective, and independent learning skills. These findings are also consistent with research by Fita et al. (2021), which showed that SSI-based PBL effectively improves critical thinking skills with a high average N-gain and significant differences. The integration of SSI and PBL encourages collaboration and active problem-solving. A meta-analysis by Badeo et al. (2022), reported that the SSI approach in science learning yielded significant effects (d = 1.08), particularly on content comprehension and decision-making. Demonstrated the effectiveness of SSI in supporting scientific literacy in contextual chemistry topics. This supports the aligning of the approach used in this e-module with the needs of relevant, reflective, and applicable science learning.

O'Reilly et al. (2022), state that critical thinking is a combination of attitudes, knowledge, and skills. This competency is represented through a number of skills, including: inference, recognizing assumptions, deduction, interpretation, and evaluation. Ardianingtyas et al. (2020) adds six indicators of critical thinking: identifying problems, gathering relevant information, developing alternative solutions, drawing conclusions, expressing opinions, and evaluating arguments. Meanwhile, Thornhill-Miller et al. (2023) emphasizes that critical thinking instruction should be directed at the ability to analyze, criticize, support ideas, reason inductively and deductively, and reach conclusions based on sound and unambiguous evidence. In this study, the critical thinking skill indicators used refer to Kumala et al. (2022), CBC framework, which has been simplified into six indicators: Focus (determining the focus of the problem), Reason (assessing reasons), Inference (assessing the logic of conclusions), Situation (understanding the context), Clarity (clarity of language), and Overview (reviewing the entire argument). These six indicators are shown in Table 6.

**Table 6.** Critical Thinking Skill Indicators

| Indicator | Description |
|---|---|
| Focus | Determining the focus or core of the problem |
| Reason | Assessing whether the reasons given are reasonable and acceptable |
| Inference | Assessing whether the conclusions drawn from those reasons are logical |
| Situation | Carefully understanding the situation or context. |
| Clarity | Ensuring that the language or explanations used are clear. |
| Overview | Reviewing the entire information or argument thoroughly |

SSI generally covers controversial scientific topics and requires moral or ethical considerations in decision-making. Problems in SSI cannot be resolved solely through scientific understanding, as these issues involve social dimensions and societal values (Owens et al., 2021). In science education, the use of SSI can enhance the connection of learning to real-life situations, strengthen students' argumentative skills, and deepen scientific literacy. Fraser et al. (2012), emphasize that the SSI approach is a development of previous science education approaches, supported by an explicit theoretical foundation, particularly from cognitive psychology and sociocultural theory. This approach emphasizes the importance of science learning that focuses not only on content but also on social and moral dimensions. The implications of this approach suggest that science and society are inseparable. Both influence each other in shaping complex issues such as biotechnology, molecular genetics, and environmental challenges resulting from population growth. These issues create a need for learning that integrates science with relevant social contexts.

According to Dusturi et al. (2024), issues categorized as socio-scientific issues (SSI) have certain characteristics that distinguish them from ordinary science issues. First, these issues have a strong scientific basis, so understanding them requires knowledge and skills in science. Second, SSI involve decision-making that can be individual or collective, as their impacts affect various levels of society. Third, these issues frequently receive media attention, indicating their relevance and urgency in everyday life. Furthermore, SSI generally contain incomplete or even debated information, thus encouraging students to be critical and open to various possibilities. Fourth, these issues span local to global scales, reinforcing the importance of a cross-regional perspective in understanding and responding to them. Fifth, SSI are also imbued with ethical values and considerations that demand moral and social considerations in the learning process. Finally, understanding SSI requires awareness of the risks and potential risks involved, making it an effective tool for developing students' critical thinking skills and scientific literacy. Examples of relevant SSI topics include: the use of single-use plastics, climate change, renewable energy, vaccination, and food safety.

These topics are relevant to students' daily lives and encourage them to think critically and make decisions based on scientific evidence. SSI-based learning provides meaningful learning experiences because it encourages students to connect their scientific knowledge to the surrounding social context. This process requires students to share ideas, build values, and actively participate in complex socio-scientific discussions (Zeidler et al., 2005). The PBL model is integrated into SSI-containing e-modules due to its advantages. This model is a constructivist model that places students in problematic situations to be solved using their existing knowledge and skills. According to Adnyani et al. (2023), PBL trains students to develop critical thinking skills, develop inquiry, and develop skills in solving problems independently and collaboratively. This model also encourages active student involvement in the learning process, emphasizing systematic information retrieval and processing.

According to Rehman et al. (2024), PBL helps students reflect on previous experiences to solve relevant problems. This approach not only builds conceptual understanding but also develops critical thinking skills, reasoning, communication, and connections between concepts. The PBL model is designed to help students develop critical thinking, problem-solving skills, and intellectual prowess. By facing real-life situations or simulations that mimic the role of adults, students are guided to become independent learners. The PBL model has several advantages, including making learning more relevant to life outside of school and training students to solve problems critically and scientifically. PBL also encourages students to think critically, analytically, creatively, and holistically because they are trained to examine problems from multiple perspectives. To facilitate students' thinking and inquiry processes, Developed five main syntaxes in the PBL model. The five steps in the Problem-Based Learning (PBL) model, as proposed by Arends, form a systematic thought process that helps students solve problems constructively.

The first step begins with orienting students to the problem. At this stage, the teacher presents a real-world, contextual problem to build students' interest in learning and establish an initial understanding of the topic. Next, the teacher organizes students for learning. In this stage, students are directed to plan investigations, assign roles, and determine problem-solving strategies, both individually and in groups. The third step is guiding independent and group investigations, where students actively collect data, analyze information, and explore solutions under the guidance of the teacher as a facilitator (Van Leeuwen & Janssen, 2019; Pedaste et al., 2015). Afterward, students develop and present the results of their investigations. These results can be presented in the form of reports, presentations, posters, or other relevant media. The final stage is analyzing and evaluating the problem-solving process, where the teacher and students jointly reflect on the learning process, evaluate the effectiveness of the formulated solutions, and relate them to real-life situations (Albay, 2019; Mazrur et al., 2024). These five steps are interconnected and form a learning cycle centered on developing critical thinking skills and in-depth conceptual understanding.

This syntax was used as the basis for developing an e-module integrated with the context of Socio-Scientific Issues. In this study, its effectiveness in improving students' critical thinking skills and scientific literacy was tested. The e-module containing Socio-Scientific Issues (SSI) using the Problem-Based Learning (PBL) model is an innovative digital learning material that integrates PBL as the primary learning framework and SSI as the core problem content. This approach is designed to strengthen 21st-century skills, particularly students' critical thinking and scientific literacy. Through the PBL framework, students are encouraged to actively investigate, analyze, and reflect on complex problems, while the SSI content presents real-life issues with controversial scientific and social dimensions. This integration ensures that students not only acquire knowledge but also experience a contextual, reflective, and meaningful learning process. The reciprocal relationship between SSI content and PBL syntax fosters a reflective process unique to digital-based learning, where students not only absorb information but also practice critically and value-based consideration of alternative solutions.

Research by Amalia et al. (2024), showed that developing a science e-module based on SSI with a PBL approach on the topic of ecosystems significantly improved students' critical thinking skills. In this study, SSI content was utilized as contextual problems that stimulated the learning process, while PBL syntax was used to structure the learning activities. Effectiveness test results showed an increase in critical thinking skills with an N-Gain value of over 0.7, which is considered high. This demonstrates that the integration of SSI and PBL in the e-module has a positive impact on students' higher-order thinking skills. The science e-module containing Socio-Scientific Issues (SSI) using the Problem-Based Learning (PBL) model used in this study was systematically developed based on the principles of instructional design and contextual learning. This module was designed to facilitate students in developing critical thinking skills and scientific literacy through learning activities that emphasize problem-solving and exploration of relevant socio-scientific issues.

The selection of SSI content in the e-module was also based on its relevance to the students' experiences and environments. Dalaila et al. (2022), developed an e-module on the immune system that addressed socio-scientific issues and found it to be valid and effective in improving scientific literacy. The N-Gain score obtained was in the moderate category, indicating an increase in understanding of scientific concepts in real-life contexts. The use of SSI as a trigger in the e-module allows students to build more meaningful connections between science and social issues. The advantage of integrating SSI and PBL in e-modules lies not only in their ability to enhance conceptual understanding, but also in their role in developing scientific attitudes, social empathy, and communication skills. Through problem-based learning activities, students practice expressing opinions, listening to other perspectives, and constructing arguments based on data. E-modules, as digital media, also offer flexibility in time and access, and facilitate engaging and interactive multimedia interactions.

Thus, SSI-based science e-modules designed based on PBL syntax represent a learning innovation that supports the development of scientific literacy competencies and critical thinking skills. This integration reflects a synthesis of constructivist educational theory and issue-based learning practices, which serve as the foundation for developing innovative and contextual teaching tools. This approach aligns with 21st-century education policy directions, which emphasize the importance of problem-solving-based learning, the integration of science with social contexts, and the use of technology to enhance learning effectiveness. The PBL model enables students to develop critical thinking skills through collaborative problem-solving, while the SSI approach links science learning to social and environmental issues relevant to students' lives. Research by Husniyyah et al. (2023), shows that the SSI approach is effective in developing students' scientific literacy and ethical awareness. Furthermore, the use of e-modules allows for visually engaging and flexible presentation of material tailored to the needs of today's learners.

E-modules can support independent learning and personalized learning, while providing content that can be accessed anytime and anywhere (Song et al., 2021). Thus, the integration of the SSI approach and the PBL model in the e-module proved effective in improving critical thinking skills and scientific literacy in junior high school students. These results confirm that contextual, problem-based, and real-world learning can address the challenges of 21st-century education**.**

## Conclusion

The results of this study indicate that a science e-module containing Socio-Scientific Issues (SSI) using the Problem-Based Learning (PBL) model is effective in improving critical thinking skills and scientific literacy in junior high school students. The significant increase in posttest scores, high gain scores, and large effect sizes indicate that the use of the e-module has a strong positive impact on student learning outcomes. Critical thinking skills experienced significant improvements, particularly in the reasoning and situational aspects, while scientific literacy increased moderately, with the highest increase in relational understanding. This demonstrates that the integration of SSI and PBL in the e-module provides a meaningful learning experience, encourages students to think reflectively, and connects scientific concepts to real-life contexts. Therefore, this e-module can be considered a valid and effective learning medium to support the achievement of 21st-century learning objectives, particularly in science education. This e-module is recommended for wider use, with further development, particularly to strengthen the coverage of basic concepts and deepen students' scientific understanding.

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N. K. H. K, I, N, K, and N. M. P., have made substantial contributions to the entire research process, including: formulation and design of the study; collection, analysis, and interpretation of data; drafting the article and critically revising its intellectual content; and final approval of the version of the article submitted for publication.

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**Conflicts of Interest**

The authors declare that there are no conflicts of interest in this research. The entire research process, from planning, data collection and analysis, to writing the article, was conducted independently without the involvement of external parties that could influence the results or interpretation of the research. The authors have no personal, professional, financial, or institutional interests that could be perceived as inappropriately influencing the representation of data or conclusions in this article. Furthermore, because this research received no funding from any party, the sponsor or funder did not play a role in the study design, data collection and analysis, writing the manuscript, or the decision to publish the results.

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