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ENHANCING CRITICAL THINKING OF ELEMENTARY SCHOOL STUDENTS IN INDONESIA THROUGH THE INTEGRATION OF SOCIO-SCIENTIFIC ISSUES-BASED INSTRUCTION IN DEEP LEARNING

APRIMORANDO O PENSAMENTO CRÍTICO DE ALUNOS DO ENSINO FUNDAMENTAL NA INDONÉSIA POR MEIO DA INTEGRAÇÃO DO ENSINO BASEADO EM QUESTÕES SOCIOCIENTÍFICAS NA APRENDIZAGEM PROFUNDA

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Abstract
Amidst the complexity of today's issues, critical thinking skills are a key competency that needs to be developed early on through learning activities that encourage analysis and reflection. This study aims to address this demand by developing and testing a science learning model based on the integration of socio-science issues and a deep learning approach. This study developed a learning model with reference to Dick and Carey's framework with four main steps taken included setting learning objectives, developing a learning model, and conducting formative and summative evaluations. Validation by experts shows a Very Valid level of suitability for all aspect. Practical testing with teachers and students proved that this model is easy to implement and supports science learning needs. Effectiveness analysis through the non-parametric Mann–Whitney U test showed similar results in both schools, marked by a significance value of < 0.001, which confirms a significant difference between the means of the two groups. The results of the study indicate that the SSI-PM integrative model has theoretical validity, good practicality, and significant effectiveness in improving students' critical thinking skills. Student involvement in controversial socio-

Resumo
Em meio à complexidade dos problemas atuais, o pensamento crítico é uma competência fundamental que precisa ser desenvolvida desde cedo por meio de atividades de aprendizagem que incentivem a análise e a reflexão. Este estudo visa atender a essa demanda, desenvolvendo e testando um modelo de aprendizagem de ciências baseado na integração de questões sociocientíficas e uma abordagem de aprendizagem profunda. O modelo de aprendizagem foi desenvolvido com base na estrutura de Dick e Carey, com quatro etapas principais: definição de objetivos de aprendizagem, desenvolvimento do modelo e realização de avaliações formativas e somativas. A validação por especialistas demonstra um nível de adequação "Muito Válido" para todos os aspectos. Testes práticos com professores e alunos comprovaram a facilidade de implementação do modelo e seu suporte às necessidades de aprendizagem de ciências. A análise de eficácia por meio do teste não paramétrico de Mann-Whitney U apresentou resultados semelhantes em ambas as escolas, com um valor de significância de < 0,001, o que confirma uma diferença significativa entre as médias dos dois grupos. Os

scientific issues presents real-life situations that require them to evaluate various considerations in the decision-making process.

keywords: Deep Learning. Elementary. Science. Socio-Scientific Issues.

resultados do estudo indicam que o modelo integrativo SSI-PM possui validade teórica, boa aplicabilidade prática e eficácia significativa no aprimoramento do pensamento crítico dos alunos. O envolvimento dos alunos em questões sociocientíficas controversas apresenta situações da vida real que exigem que eles avaliem diversas considerações no processo de tomada de decisão.

Palavras-chave: *Aprendizagem Profunda. Ensino Fundamental. Ciências. Questões Sociocientíficas.*

1 INTRODUCTION

Critical thinking is essential in facing the era of technological disruption, information, and rapid social change, complex problems, so that individuals can think logically and systematically in analyzing information and making evidence-based decisions (Facione, 2013; Lai, 2011). Critical thinking as part of life and work skills can contribute to academic and career success (Shaw *et al*., 2020), and is the foundation for other 21st-century skills (Herawati *et al*., 2020). Critical thinking is important to be instilled from an early age (OECD, 2023) to shape students who are careful, responsive, and able to face global challenges with deep thinking (Kemdikdasmen, 2025).

Deep learning in the Indonesian context known as Pembelajaran Mendalam (PM), which began its implementation in 2024, is an effort to improve the quality of education in Indonesia and places special emphasis on critical thinking. PM is also a response to international reports indicating that Indonesian students' critical thinking skills and analytical literacy are still low. This aligns with the results of preliminary research in this study (Sinyanyuri *et al*., 2025) which showed that elementary school students' critical thinking skills are still low. Furthermore, the learning process is generally conventional, emphasizing memorization and minimal scientific reading activities, thus under supporting the development of critical thinking (Swandi *et al*., 2025). To overcome these critical thinking skills issues, an effective, student-centered learning model is needed (Ananda *et al*., 2023; Chew *et al*., 2020), such as Socio-Scientific Issues-based instruction (SSI-BI) (Karpudewan & Chan, 2022; Kim & Kim, 2021; Walker & Zeidler, 2007).

Students' ability to solve complex problems such as SSI must be supported by a deep understanding of the content of the material being discussed (Ananda *et al*., 2023;

Varenina *et al*., 2021). PM is a learning approach that encourages students to actively construct knowledge through conceptual understanding, meaningful connections, and reflection. Through PM, students are required to have the ability to understand and evaluate relevant statements logically and rationally during the problem-solving or decision-making process, and engage in exploratory and reflective thinking activities (Shaw *et al*., 2020). This encourages critical reasoning skills that must begin with student involvement in a problem (Alsaleh, 2020), practice critical problem-solving, and be integrated into the curriculum (O'Reilly *et al*., 2022) using effective supporting teaching methods (Kinoshita, 2022).

This study aims to address the identified challenges by developing and evaluating the effectiveness of a learning model that integrates SSI-BI into deep learning, resulting in CIRCLE syntax, to improve elementary school students' critical thinking skills. The development of the CIRCLE learning model can be an effective combination in developing skills to face global challenges in the modern era (Retno & Saputro, 2025) and providing opportunities to learn science in cross-cultural and cross-disciplinary contexts (Mang *et al*., 2021).

1.1 Research questions

Referring to the previous explanation, this study attempts to answer several key questions:

1. How was the learning model developed?
2. How valid is the developed learning model?
3. How practical is the learning model when implemented?
4. How effective is the learning model in improving students' critical thinking skills?

2 METHOD

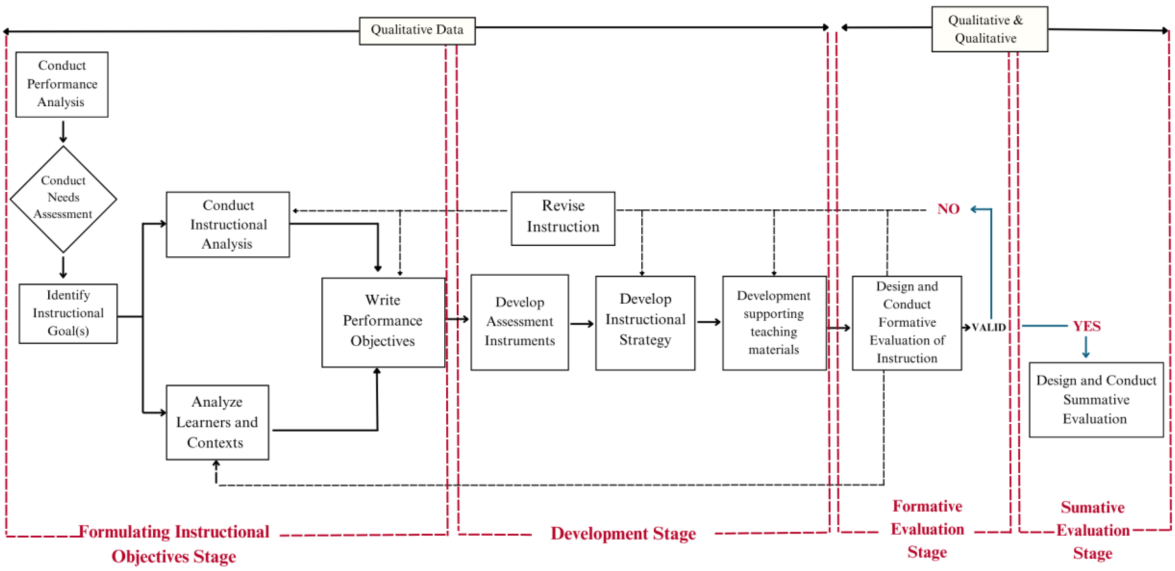
2.1 Research design

This study is research and development type using the Dick and Carey model. This model is commonly used in instructional design development because it provides clear and logical direction (Dick *et al*., 2015). The purpose of this study is to develop a valid, practical, and effective learning model. Modifications to the Dick and Carey model and front-end analysis resulted in four main stages that form the basis for developing the instructional model in this study: formulating instructional objectives, development, formative evaluation, and summative evaluation.

The research process is visualized in Figure 1, which shows the combination of qualitative and quantitative methods throughout the entire process. At the stage of analyzing needs and setting learning objectives, qualitative methods were used in the form of in-depth interviews, document reviews, and triangulation involving students, teachers, and school principals. The information obtained then became the basis for formulating the conceptual design and framework of the learning model.

Figure 1

Research Design



The research process began with a needs analysis to formulate model development, followed by the preparation of Draft 1. The draft was validated by experts and revised based on their findings. Practitioner validation was conducted through group discussions involving 10 teachers. The results of expert and practitioner validation produced Draft 2. Draft 2 was then tested through individual, small group, and large group trials. During the trials, the same teacher facilitated learning, monitored student participation, and provided feedback for finalizing the model.

During the field implementation stage, two schools participated with a total of 120 students divided into experimental and control groups, each consisting of 30 students per school. All students received uniform learning devices and evaluation instruments, including pre-tests, post-tests, and worksheets. Each trial phase produced quantitative data—primarily pre-test and post-test scores and practicality scores as well as qualitative data in the form of feedback, observations, and group discussions. Analysis of both types of data ensured that the final model was built on empirical evidence and student input, making it contextually relevant and pedagogically sound.

2.2 Research subject

This study involved teachers and students from two primary schools in Indonesia. Ten teachers participated, consisting of three males and seven females. The trials were conducted in stages, starting with one-on-one trials (four students), small group trials (eight students), and large group trials (30 students). The field implementation stage covered two schools with 60 students each, divided into experimental classes using the CIRCLE model and control classes using conventional learning. Although the trial participants differed at each stage, all had comparable characteristics, namely fifth-grade students with relatively similar initial critical thinking skills.

2.3 Instruments

The instruments used included measurements of validity, practicality, and effectiveness, with an emphasis on the critical thinking skills of primary school students. During the process of formulating and developing learning objectives, qualitative methods including document analysis, interviews, and school data triangulation were utilized to gain a comprehensive understanding. The first objective, validity, used an expert validation rubric to evaluate the learning model design and student worksheet. The expert validation rubric evaluated the learning model components, content, and the theory of SSI and PM relevance. Meanwhile, for the student worksheets, the validation rubric consisted of three types: content validation, language validation, and media validation. Validity was measured using a 5-point Likert scale.

Practicality was evaluated through user responses obtained from questionnaires completed by students and teachers during the field trial and implementation stages. The level of practicality was determined based on user responses regarding the usefulness, ease of use, and enjoyment of the CIRCLE learning model and analyzed using a 5-point Likert scale. Effectiveness was determined using pre- and post-tests based on critical thinking indicators. These instruments measured six indicators of critical thinking: identifying problems, collecting and analyzing data, assessing dominant concepts, evaluating arguments, drawing conclusions, and reflecting. The critical thinking test uses an essay format adapted from (Herman *et al*., 2020; Walker & Zeidler, 2007).

2.4 Data analysis

The final validity score used five categories: Very poor/invalid (X ≤ 35), Poor/less valid (36% - 53%), quite valid/acceptable (53% - 68%), good/valid (69% - 84%), and Very good/very valid (X > 84%) (Asmianto *et al*., 2022). To determine the level of practicality, the scores obtained from student and teacher assessments are compared with the maximum score, resulting in a percentage that is grouped into five levels: impractical (0–20), less practical (21–40), fairly practical (41–60), practical (61–80), and very practical (81–100) (Novitra *et al*., 2021; Swandi *et al*., 2025).

Critical thinking scores are calculated by comparing each student's score to the maximum score. Next, the difference between the pre-test and post-test scores is used to determine the gain value. The gain value is classified into five categories: decline ($-1.00 \leq g < 0.00$), no improvement ($g = 0.00$), low ($0.00 < g < 0.30$), moderate ($0.30 \leq g < 0.70$), and high ($0.70 \leq g \leq 1.00$) (Sukarelawa *et al*., 2024). To assess the effectiveness of the CIRCLE model in improving critical thinking skills, an independent t-test was conducted on the gain value to compare the improvement between the experimental class and the control class. Before the analysis was conducted, the initial abilities of the two groups were tested for equality using an independent t-test or Mann–Whitney U test. If the pretest results showed no significant differences, the analysis was continued to identify differences in critical thinking ability improvement based on a t-test of the gain values.

3 RESULTS

The explanation in the results section refers to the four research questions that have been presented as follows.

3.1 Development of the CIRCLE learning model

The development of the CIRCLE learning model begins with determining instructional objectives developed based on an analysis of students' needs, performance, and characteristics conducted through surveys, document analysis, observation, and FGD. Based on the results of the analysis of student characteristics and performance, the critical thinking indicators that will be developed through this learning model are identifying problems, collecting and analyzing data, assessing dominant concepts, evaluating arguments, drawing conclusions, and reflecting. These instructional objectives serve as a guideline in developing learning syntax, as conveyed by (Inch & Tudor, 2015) who emphasize the critical thinking cycle to design approaches to address the need for increased critical thinking.

The next stage is developing an instrument to measure the achievement of instructional objectives. This is followed by integrating the SSI-BI and PM learning experiences to encourage critical thinking, resulting in a learning principle and syntax consisting of six stages, an acronym for CIRCLE: Concern, Investigation, Reinforcement, Connection, Loudness, and Evaluation. Furthermore, the learning model resulting from the integration of SSI-BI and PM is called CIRCLE. The integration process is summarized in the table 1.

Table 1

Integration SSI-BI in PM

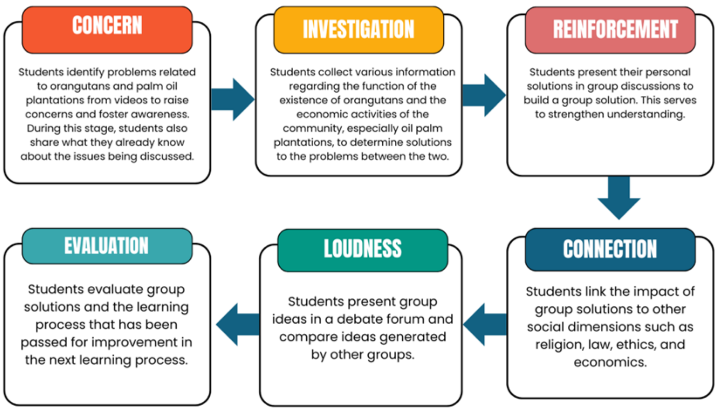
Kemdikdasmen (2025)	Presley *et al*. (2013)	**CIRCLE Learning Model**	
		Principles	**Syntax**
Understanding	Building instruction around a compelling issue. Presenting the problem (issue) first	Active prior knowledge	**Concern** (Presenting problems from the issue being discussed to raise concerns and find out students' initial understanding)
	Collecting and/or analyzing scientific data related to the issue being considered.	Construct knowledge	Investigation (collect data to find solutions)
Apllying	Engaging in higher-order practices (e.g., reasoning, argumentation, decision making, and/or position taking)		Reinforcement (discussing to find group solutions as a way to strengthen individual understanding)
	Negotiating social (e.g., political and economic)	Integrated / connecting	Connection

	dimensions of the issue being considered.		(Linking the impact of group solutions to the social dimension)
	Confronting scientific ideas and theories related to the issue being considered.	Develop mastery	Loudness (Voicing the group's final idea)
Reflecting	Providing a culminating experience	Evaluation	Evaluation (evaluate the solutions and learning processes that have been passed)

Analysis of current science policies and curricula was also carried out, which require integration with social studies and SSI topics. This article explains the implementation of the CIRCLE learning model with one of the learning topics related to SSI regarding the controversial issue of saving orangutans or oil palm plantations. Orangutans, as one of Indonesia's endemic animals, are currently nearing extinction due to the reduction of forests due to their use for palm plantations. Meanwhile, Indonesia, as one of the world's largest palm oil producers, receives significant foreign exchange income from this. The purpose of learning this topic is for students to be directly involved in experiences in authentic environments (Lave & Wenger, 1991; Miner & Nicodemus, 2021; Patel, 2018) through participation in social situations that are constantly evolving and need to be updated so that they are ready to be fully involved in solving problems in the real context of their lives as responsible citizens (legitimate peripheral participation). The learning design is arranged according to the syntax for the learning as illustrated by the figure 2.

Figure 2

Learning Syntax pf CIRCLE Model for the Topic of Saving Orangutans or Palm Plantation



3.2 Validity of CIRCLE learning model

The CIRCLE learning model was validated by four instructional design experts (Validator=Va) using one type of learning model assessment rubric. Meanwhile, the student worksheets were validated by nine experts using three types of assessment rubrics to evaluate the content, language, and media. Each type of assessment rubric for the student worksheets was assessed by three experts. Validation was carried out through discussions and written assessments until the validator declared the developed product valid. Table 2 shows the results of the CIRCLE learning model validation analysis.

Table 2

Result of Validation Model by Expert

Assessment Aspect	**Score**				**Average**	**%**
	Va1	**Va2**	**Va3**	**Va4**		
Learning Objectives and Materials	20	20	20	20	20,0	16,7
Learning Model Components	15	12	14	14	13,8	11,5
Theoretical Support	25	25	23	24	24.3	20.2
Syntax Development	10	8	8	8	8,5	7,1
Social System	10	9	8	8	8,8	7,3
Reaction Principle	15	15	13	12	13,8	11,5
Support system	13	13	15	15	14,0	11,7
Application	9	8	10	9	9,0	7,5
Total	117	110	111	110	112	**93,3**
Criteria						**Very Valid**
Total Theoretical Score = 120						

Based on the validation results, the CIRCLE learning model is categorized as very valid. This means the CIRCLE learning model design is highly suitable for use in the learning process. The highest contributions to the validation score were, respectively, demonstrated by the theoretical support, learning model component, and support system aspects.

The table 3 shows a summary of the results of expert validation of material content, language and media for student worksheets.

Table 3

Result of Validation Student Worksheet by Expert

Assessment Aspect	**Validity**	
	Overall Average (%)	Criteria
Content	88	Very Valid
Language	90	Very Valid
Media	83,5	Very Valid

The validity of the student worksheets was very high, especially in terms of language, which received the highest score. This confirms that the learning model and worksheets developed meet the eligibility criteria and are ready for implementation. These findings also show that the development of the model is supported by a strong theoretical basis.

3.3 Practically of CIRCLE learning model

The next stage was to evaluate the practicality of the model and student worksheets through assessment by primary school science teachers. The results of the analysis, shown in Table 4, indicate that both tools are in the highly practical category. The aspects of usefulness, ease of application, and level of satisfaction each scored above 94%, with usefulness recording the highest average. The student worksheets were also rated as highly practical in terms of content, language, and user satisfaction, with the material aspect receiving the highest score, particularly in relation to its suitability for student competencies and needs. Overall, these results indicate that the learning tools developed are not only valid but also highly feasible and easy to implement in SSI-based science learning in PM.

Table 4

Practicality Result According to The Teachers

Assessment Aspect	Average Reponse	
	Overall Average (%)	**Criteria**
CIRCLE Learning Model		
Usefulness in enhancing critical thinking and deep learning	100	Very Valid
Ease of teachers in understanding and implementing	94,7	Very Valid
Teacher satisfaction in using learning models and will recommend to other teachers	98	Very Valid
Student Worksheet		
Suitability of material to student competencies and needs	99	Very High
Accuracy and appropriateness of language use	98	Very High
Clarity and satisfaction with illustrations and layout	97	Very High

The results of the practicality assessment according to students are shown in Table 5.

Table 5

Practicality Result According to the Students

Assessment Aspect	Average Reponse	
	Overall Average (%)	Criteria
The worksheets provided me with a good understanding and developed my problem-solving skills.	93	Very High
The worksheets were easy to understand, both in terms of language, material, and assignments.	85	Very High
The worksheets were interesting, and I enjoyed using it.	92	Very High

The results of the practicality of the CIRCLE learning model-based worksheets according to students showed that all aspects assessed were categorized as "very high." The ease aspect received the lowest score. However, students' opinions regarding learning were considered not easy, but this was related to students' difficulty in finding ideas rather than difficulties in the learning process. Overall, the data showed that students reacted very positively to the CIRCLE learning model-based worksheets, both in terms of content, usability, ease, and satisfaction. This suggests that appropriate instructional design can improve student engagement and cognitive outcomes (Krajcik & Delen, 2016; Swandi *et al.*, 2025).

3.4 Effectiveness of CIRCLE learning model

The effectiveness test was conducted to prove that research products that have been declared valid and practical can have an impact on improving learning outcomes (Aka, 2019) seen from the increase in the achievement of competency indicators (Akker *et al*., 1999; Plomp & Nieveen, 2007; van den Akker *et al*., 2006). The effectiveness test in this study was conducted at the summative evaluation stage as empirical evidence regarding the product's ability to produce significant learning impacts (Dick *et al*., 2015). The effectiveness test was conducted in two schools, namely school A and school B, which was measured by looking at the gain value and t-test using the SPSS 29. The average gain value from both schools can be seen in the table 6.

Table 6

Comparison of Gain Values

Descriptive statistics	**School A**		**School B**	
	Control class	Experimental class	Control class	Experimental class
Mean	0.0999	0.3917	0.0926	0.4649
Std. deviation	0.15274	0.2120	0.11419	0.12570

Based on the table, the average gain scores for the experimental classes at both schools are in the moderate category. Meanwhile, the average gain scores for the control classes are in the low category. These results indicate that the CIRCLE learning model used in the experimental classes is more effective in improving students' critical thinking than the conventional learning model used in the control classes.

The next step is to ensure that the initial abilities of the experimental and control groups are comparable. At School A, the normality test showed that only the control class was normally distributed (sig. 0.200), while the experimental class was not (sig. 0.001), so a Mann–Whitney U test was conducted. The sig. (0.578 > 0.05) indicates no significant difference in the pre-test of the two groups, so both are considered equivalent and eligible for the N-gain-based independent t-test.

At School B, both classes did not meet the normality assumption (sig. 0.002 and 0.006), so the analysis also used the Mann–Whitney U test. The results (sig. 0.698 > 0.05) showed that the initial abilities of the two classes did not differ significantly. Thus, the independent t-test based on N-gain could be applied.

The next step is to analyze the gain values in both classes. For Class A, the Kolmogorov–Smirnov normality test shows that the experimental class has a significance value of 0.043 < 0.05, while the control class has a significance value of 0.155 > 0.05. This means that the data in the experimental class is not normally distributed. Since the normality assumption was not met, the difference analysis was performed using the Mann–Whitney U non-parametric test. The test results showed a significance value < 0.001, indicating a significant difference between the two groups. Thus, the critical thinking skills of students in the experimental class using the CIRCLE learning model were proven to be higher than those of students in the control class who learned through conventional methods.

The next analysis was conducted on class B. The Kolmogorov–Smirnov normality test showed that the experimental class had a significance value of 0.200 > 0.05, indicating that the data was normally distributed. In contrast, the control class obtained a significance value of 0.008 < 0.05, indicating that the data was not normally distributed. Because the data distribution did not meet the normality assumption in both groups, the comparison was performed using the non-parametric Mann–Whitney U test. The test results showed a significance value < 0.001, indicating that the increase in critical thinking skills of students in the experimental class using the CIRCLE model was significantly higher than that of students in the control class who learned through conventional methods.

4 DISCUSSION

The development of the CIRCLE model in this study follows the Dick and Carey instructional design model, which has become a standard in instructional development (Branch & Dousay, 2015). This model has a systematic and structured approach, consisting of interacting components, ranging from setting learning objectives and analyzing needs, developing materials, to formative and summative evaluation. This model pays special attention to student characteristics, ensuring that the developed instructional objectives are aligned with their needs. By considering the initial conditions of participants, triangulating various data sources, involving validation from experts, and implementing field trials, this research not only produced applicable pedagogical innovations but also contributed methodologically by demonstrating the use of a development model to design solutions aligned with theoretical frameworks and real classroom needs. The CIRCLE model was developed as a breakthrough in learning that responds to the challenges of science learning in primary schools. Through the integration of the SSI-BI and Deep Learning approaches, this model is aimed at stimulating students' critical thinking skills. A comprehensive evaluation process—covering validity, practicality, and effectiveness tests—was carried out to ensure that the model is feasible and ready to be implemented in learning.

Validation results indicate that the CIRCLE-based learning model and student worksheets fall into the "highly valid" category, reflecting the alignment between the design and the underlying educational theory. This aligns with the views of Salawu *et al*. (2013) who emphasized the importance of a theoretical foundation in developing a conceptual framework for learning models. High validity was also evident in the student worksheets, which facilitated student understanding of the material and developed critical thinking through illustrations, communicative language, and a logical and systematic structure. Therefore, the developed learning tools are theoretically valid and feasible for implementation (Shernoff *et al*., 2017; Swandi *et al*., 2025).

The practicality of this model was determined based on teacher and student responses to the CIRCLE-based learning model and student worksheets. Practicality encompasses usability, ease of use, and satisfaction with the learning tools, which are factors influencing success. Teacher responses indicated that the CIRCLE-based learning model and worksheets were easy to use, useful, and teachers were satisfied and happy. Students also responded positively to the learning tools used. This finding strengthens the findings Desstya *et al*. (2024) and Georgiou & Kyza (2023) which emphasizes the importance of supporting an active and integrated learning environment in the implementation of SSI.

In terms of effectiveness, the CIRCLE learning model has proven effective in improving elementary school students' critical thinking in science. Through the CIRCLE learning stages, students are invited to formulate questions based on texts, such as what happens to orangutans if we allow palm oil plantations to continue to expand? What are the consequences if we stop palm oil production? Who should be responsible for the problem? Students then practice providing simple clarifications based on evidence or data that has been collected. Next, students must confront ideas or concepts with various social dimensions before making decisions regarding solutions to the problem. Several solutions proposed by students, such as limiting oil palm plantation land, establishing strict rules, and managing land specifically for orangutans, demonstrate students' success in solving problems. This indicates that students are able to identify problems (Concern stage), explore their experiences based on given phenomena (Investigation stage), assess from various perspectives (Connecting stage), evaluate arguments (Loudness stage), and draw conclusions as indicators of critical thinking. The results of this study indicate that to develop students' critical thinking skills, this is done through learning experiences with the first step being problem-solving activities. This reinforces the research Fitriani *et al*. (2020) and Kardoyo *et al*. (2020).

The reinforcement stage in the CIRCLE learning model emphasizes discussion and the exchange of ideas. Interaction between group members encourages the exchange of ideas and can lead to improved critical thinking skills. Mugabekazi *et al*. (2025), also demonstrate this. This stage also allows students to self-reflect and evaluate their problem-solving process by comparing the ideas with those of other groups. This is important for the success of learning implementation due to the provision of authentic problems (Häyrynen *et al*., 2021; Zheng *et al*., 2024), and feedback (Dawson *et al*., 2021; Fitriani *et al*., 2020). SSI as the basis of the CIRCLE learning model helps students use scientific knowledge in a broader social context and reason about how the interaction of science and social factors can influence students' positions on complex issues. This approach is important in bridging disciplinary knowledge and everyday decision-making, and has important implications for science teaching for scientific literacy (Ke *et al*., 2021).

5 CONCLUSION

Based on the results, it can be concluded that the developed learning model has a conceptual basis and is empirically proven to improve critical thinking in elementary school students. The results of the development are realized in the form of a conceptual framework that integrates SSI-BI with the PM approach and produces a learning syntax called CIRCLE. The CIRCLE learning model is designed to address the needs of science learning that supports the improvement of critical thinking.

Expert assessment of the model tool shows that its validity level is very high, covering aspects of theory, learning syntax structure, material suitability, language clarity, and media quality. In addition, the practicality of the model is also rated very highly by teachers and students, confirming that this model is easy to implement and relevant to learning needs in schools.

The effectiveness of this learning model is evident from the significant improvement in students' critical thinking skills when compared to conventional approaches, as demonstrated by the gain scores and t-test results. On this basis, this model is suitable for application in science education in primary schools as an innovative strategy that can overcome various limitations while strengthening critical thinking skills. The findings of this study have strategic implications for primary schools, particularly in the implementation of science learning that is contextual, interactive, and based on current issues.

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Both authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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